ELEMENTARY

PRACTICAL PHYSICS

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ELEMENTARY PRACTICAL CHEMISTRY:

A LABORATORY MANUAL FOR USE IN ORGANIZED SCIENCE SCHOOLS.

By G. S. NEWTH, F.I.C., F.C.S., Demonstrator in the Royal College of Science, London; Assistant-Examiner in Chemistry, Science and Art Department.

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PRACTICAL PHYSICS

A LABORATORY MANUAL

FOR

USE IN ORGANIZED SCIENCE SCHOOLS

BY

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PREFACE

THE methods of teaching elementary physics in this country are at the present moment undergoing an important change, owing, in a great measure, to the recent action of the Science and Art Department in requiring even the most elementary students—in organized science schools—to go through a course of practical physics, and of the University of London in requiring a knowledge of the practical use of instruments from the candidates at the preliminary and intermediate examinations in science. It is, therefore, now necessary that the individual members of the classes should be taught to themselves perform the experiments, instead of the teacher, as has been hitherto commonly the practice, alone performing the experiments in the presence of the class.

In order to satisfactorily conduct such a class, where a number of students are working at elementary practical physics, and where, therefore, the teacher cannot devote his time exclusively to one or two, it is absolutely necessary that the students should be supplied with written instructions as to the method in which the experiments are to be performed, particularly if, as is generally the case, all the students are not engaged on the same experiment; and it is with a view of supplying such instruction in the form of a laboratory manual that this book has been written. Although in most cases a few introductory remarks, which have purposely been made

as short as possible, are given, the bo[illegible] intended to replace personal instruction, which should consist of both individual supervision and of general explanations given to the whole class, either in the form of lectures or demonstrations.

The experiments have been chosen with a view of obtaining, wherever it was possible, a *quantitative* answer, and are generally of such a nature that a careful worker will be able to get satisfactory results. This is a most important point, for if there is one thing more than another which tends to disappoint beginners and to get them into a careless and slipshod method of working, it is performing a number of experiments in which the results can only be depended upon to a very rough approximation, so that a good result is more a matter of luck than of careful work.

Although the book is intended for the student rather than the teacher, it is hoped that the list of apparatus, etc., required for each experiment, given at the commencement of the exercises, and the information given in the Appendix, will be found of use to the teacher. As will be seen from the lists of apparatus given in the Appendix, the cost of instituting such a course as described is not very great; and, after the instruments have once been obtained, the annual outlay necessary to keep the laboratory in an efficient condition is very small.

It will probably be found best to let the students work in pairs, and it is, perhaps, scarcely necessary to add that a little judgment and forethought exercised in arranging the pairs will greatly assist the management of the class. In the following pages no attempt has been made to divide the exercises into lessons, since the amount of work which can be got through in a lesson by different pupils varies so much. A great deal of time will be saved if each pair of students is told at the end of each lesson the experiment which they will have to perform at the next lesson, so that they may in the mean time read up

the instructions, etc., and thus be able to start work without loss of time on entering the laboratory. To carry out this arrangement, it is as well to have as many cards as there are sets of apparatus available, with the number of the exercise written upon them, and to distribute these cards at the end of each lesson. If this method is adopted, there is no danger of simultaneously setting the same experiment more times than the apparatus will allow.

The figures have in most cases been prepared from photographs of actual pieces of apparatus which have been found to work well. I have, however, to thank Professor Worthington, F.R.S., for permission to use a few figures which are taken from his "Physical Laboratory Practice." I have also to thank my brother, Mr. James Douglas Watson, F.I.A., for much assistance in preparing the manuscript for the press.

W. W.

ROYAL COLLEGE OF SCIENCE, LONDON.

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ELEMENTARY PRACTICAL PHYSICS.

PART I.—MENSURATION.

SECTION I.—THE MEASUREMENT OF LENGTH.

PHYSICS has been defined as the Science of Measurement, and it is this aspect of the subject which will be primarily dealt with in these pages—the first measurement with which we shall deal being that of distance, or length.

In order to be able to express the distance between two points it is necessary to choose some fixed length, and to say that the distance is so many times this fixed length. Thus we say that the distance between two places is a hundred paces, meaning that a hundred times the distance which we can step would reach from one place to the other. Any fixed length which is made use of in this way as a standard of reference when expressing lengths or distance is called a *unit of length.*

In Great Britain the standard unit of length is called the yard, and is the distance between two very fine marks on a certain metal bar which is carefully preserved at the Standards Office of the Board of Trade, at Westminster.

Suppose we had a number of sticks of wood, the length of each piece being a yard, and we found that fourteen of these sticks, when placed end to end, stretched in a straight line from a spot, A, to another spot, B. Then the distance from A to B, or the length AB, would be fourteen times the unit of length, in this case the yard. The distance from A to B is

therefore 14 yards. It is important to notice that the record of the length AB consists of two distinct parts: first, of a number (14) which tells us the number of times the unit is contained in the length AB; secondly, of a word (yard) which tells us what particular length we have used as our unit. All records of measurements, no matter what the quantity measured may be, must always consist of two such parts, viz. (1) a number, (2) the name of the unit.

The distance between the end division-lines of the "yard" scale with which you are supplied is a yard. Since, however, for many measurements either a smaller or larger unit than the yard is convenient, certain subdivisions and multiples of the yard have received special names, and are used as units of length. The connection between these units and the yard is shown in the following table:—

$\frac{1}{3}$ of a yard is called a foot.
$\frac{1}{36}$ of a yard is called an inch.
1760 yards are called a mile.

We may express the same facts otherwise, thus—

12 inches = 1 foot.
3 feet = 1 yard.
1760 yards = 1 mile.

If you examine a yard scale it will generally be found that, besides the numbered division-lines, marking the inches, there are other lines which subdivide each inch into a number of equal parts. The most usual number of parts into which the inch is subdivided are either 8, 10, or 16. No special names are given to these fractions of an inch, but they are referred to simply as eighths, tenths, or sixteenths, as the case may be. For reasons which will be seen later on, the most convenient scale for our purpose is one in which each inch is subdivided into ten equal parts. It is, however, sometimes necessary to measure a length to within less than a tenth of an inch. Under such circumstances we may *imagine* each of the tenths further subdivided into ten equal parts, and thus estimate to the nearest tenth of a division the amount by which the given length exceeds the nearest whole tenth of an inch. After a little practice this subdivision by eye will

become fairly easy, so that a length may be measured to within a tenth of one of the smallest divisions of the scale.

In recording the results of measurements, and in almost all calculations, it will be found best to use the decimal notation in the place of vulgar fractions. Thus, instead of ½ write 0·5, etc. Suppose we find, on measurement, that a certain distance is greater than one inch and seven-tenths, but less than one inch and eight-tenths, and we estimate by eye that the excess over one inch and seven-tenths is equal to 3 tenths of a tenth of an inch: then we may write down the length as being 1 in. + 0·7 in. + 0·3 of a tenth of an inch. However, since if each tenth of an inch were divided into ten parts there would be a hundred of such parts in an inch, we may look upon 0·3 of a tenth of an inch as 3 hundredths of an inch, which may be written 0·03, for in the decimal notation figures written in the second place to the right of the decimal point represent hundredths. Thus the above length can be written 1·73 inches.

EXERCISE 1.—*The yard and its subdivisions.*

Apparatus:—Yard scale, divided into tenths of an inch.

Examine the yard scale; the long numbered divisions mark the inches. Count how many inches there are in the yard. Into how many equal parts is each inch divided? Draw in your note-book straight lines 1 inch and 6 inches long respectively. How many times is each of these lines contained (1) in a foot, (2) in a yard?

Measure the length and breadth of your work-table, also the length and breadth of the room.

Metric Units of Length.—In most countries except Great Britain the unit of length generally employed is called the *metre*, and is equal to about thirty-nine inches.[1] The metre was originally chosen as representing one ten-millionth of the distance from the pole to the equator, measured along the surface of the earth. The use of the metre as a unit of length is rapidly spreading, even in Great Britain; the chief reason being, not that the metre itself is a more convenient

[1] The use of the metre in Great Britain as a unit of length has also been authorized by Act of Parliament.

length than the yard, but that the subdivisions of the metre are more convenient than the subdivisions of the yard.

The metre is divided into ten parts, each of which is called a *decimetre;* a decimetre is divided into ten *centimetres,* and a centimetre into ten *millimetres.* For measuring long distances the *kilometre* (= 1000 metres) is usually employed.

Thus the table of length according to the metric system is as follows:—

10 millimetres = 1 centimetre.
10 centimetres = 1 decimetre.
10 decimetres = 1 metre.
1000 metres = 1 kilometre.[1]

The advantage of the above method of subdivision is the ease with which a length may be written down in terms of any one of the above units, and, if necessary, converted into either of the other units. Thus a length of, say, 3 metres, 1 decimetre, 8 centimetres, and 4 millimetres can be written—

3·184 metres
or 31·84 decimetres
or 318·4 centimetres
or 3184 millimetres.

EXERCISE 2.—*The metre and its subdivisions.*

Apparatus :—Metre scale divided into millimetres.

Examine the metre scale; the numbered divisions mark the centimetres. In your note-book draw straight lines one centimetre and one decimetre long. Also draw a straight line 0.138 m. long.

Measure the length and breadth of the top of your table and of the room in metric units.

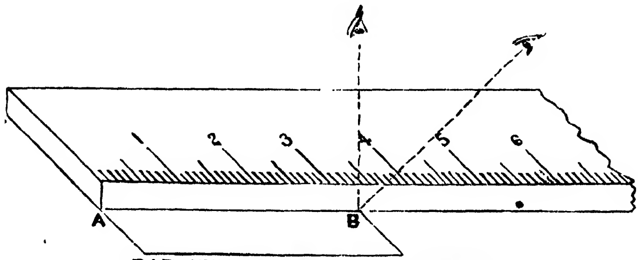
Method of using the Scale.—When measuring the distance between two points it is important to hold the scale correctly, or it will be impossible to obtain accurate results.

In the first place, the end of the scale is seldom cut quite square, the last division being generally too short. Do not therefore attempt to place the end of the scale at one of the given points and read off the distance to the other point; but

[1] The following abbreviations are generally employed: m. = metre, dm. = decimetre, cm. = centimetre, mm. = millimetre.

set the scale so that the first point is at the first or tenth centimetre or inch division, and take the reading on the scale opposite the second point. From this reading the reading at the first point will have to be subtracted to give the length between the points.

Secondly, if the scale is placed flat on the surface on which the two points are marked an error will probably be made in the readings, due to the thickness of the rule. The way this error may arise is illustrated in Fig. 1. If, when taking the

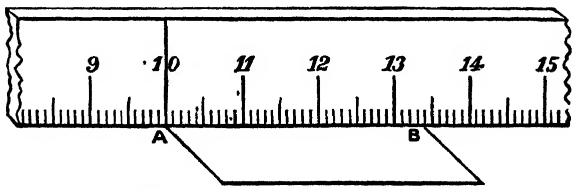


BAD WAY OF USING THE SCALE.

FIG. 1.

reading on the scale corresponding to B, the eye is placed exactly over B, a correct value, 3·35 cm., will be obtained. On the other hand, if the eye is not exactly over B, the reading obtained will be either greater or less than 3·35 cm. according to the position of the eye.

The correct way of using the scale is shown in Fig. 2, where the position of the eye will not affect the reading obtained, and the end division, which may be inaccurate, is not made use of.



GOOD WAY OF USING THE SCALE.

FIG. 2.

EXERCISE 3.—*Method of using a scale.*

Apparatus :—Yard and metre scales; piece of cardboard with three small crosses placed in a straight line, and lettered A, B, and C.

Make several measurements, in British and metric units, of the distances between the points A and B, B and C, and A and C, starting each time at a different division of the scale, and making a careful estimate of the tenths of the smallest division of the scale; *i.e.* estimate by eye to the nearest tenth of a millimetre or hundredth of an inch. Enter your results in a table, as in the following example :—

No. of Experiment.	Reading of Scale for		Difference of Readings of Scale = length AB.
	A.	B.	
1	1·00 cm.	23·12 cm.	22·12 cm.
2	2·00 ,,	24·14 ,,	22·14 ,,
3	4·00 ,,	26·12 ,,	22·12 ,,
4	3·00 ,,	25·13 ,,	22·13 ,,

Calculation of the Mean Value.—It will be noticed that the values obtained in the last column of the table in the previous exercise are not all equal. This is due to slight errors in adjusting the position of the scale at the point A, and in estimating the fractions of a millimetre at B. In such a case we take, as the distance between A and B, the average or mean of all the measurements. To obtain the mean add all the results together, and divide the sum by the number of results. In the above example the sum of the results is 88·51. Dividing by 4, the mean value is 22·127 . . . c.m. In performing the division it will be noted that we have stopped at the third place of decimals. In this case a digit in the second place represents hundredths of a centimetre, and, since our measurements were only taken to the nearest hundredth, it is unnecessary to carry on the division beyond the next place of decimals, *i.e.* to the nearest thousandth. Since, however, we have only measured to within one-hundredth of a centimetre, we are only entitled to record the result to the nearest hundredth, and so the mean value obtained is 22·13. We write three hundredths because we have seen that if we continue the division the digit after the

2 in the second place is a 7, and hence 22·13 is a more correct value than 22·12. Whenever a number of measurements are taken of the same quantity the mean must be calculated, and entered in your note-book.

Calculate the mean value for the distances AB, BC, and AC in the last exercise, and see how near the sum of the values obtained for AB and BC is to the value obtained for AC.

EXERCISE 4.—*To compare the British and Metric units of length.*

Apparatus:—Metre and yard scales.

Place the yard and metre scales side by side with the graduated edges in contact, and, taking the end divisions of the yard scale as the points A and B of the last exercise, determine the length of the yard in centimetres. Repeat the measurement three or four times, and enter the results in a table similar to that used in the previous exercise.

From the mean of the values obtained for the number of centimetres in a yard, calculate the number of centimetres in a foot, and in an inch. Also calculate the number of inches in a metre. Hence fill in the spaces in the following table:—

1 yard = ... cm.	1 cm. = ... in.
1 foot = ... cm.	1 metre = ... in.
1 inch = ... cm.	

The Use of Compasses or Dividers for measuring Lengths.—It is sometimes impossible to apply a scale directly to the object to be measured. For instance, if it be necessary

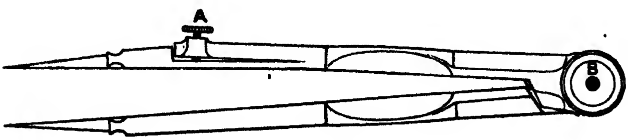


FIG. 3. (½.)

to measure the distance between two marks on a small tray where the raised edge prevents the use of a scale, we may make use of the instrument shown in Fig. 3, and called a pair

of hair-dividers. The legs of the instrument are hinged at B, and the point of one of them can be moved through a small distance by turning the screw A. When using the dividers, say, to measure the distance between two marks, M and N, one point is placed at M, and the dividers are opened till the other point is near N. Then, by turning the screw A, this point is adjusted till it exactly coincides with N. The dividers are then placed so that one point rests on one of the divisions of a divided scale, and the position of the other point is read off.

EXERCISE 5.—*Use of dividers.*

Apparatus :—Hair-dividers ; scale.

Measure, by means of the dividers, the distance between the points A, B, and C on the card used in Exercise 3.

Enter your results in a table, as below :—

No. of Experiment.	Scale Reading for		Difference of Readings = Distance between the given Points.
	Leg A.	Leg B.	
1			
2			
3			

Measurement of the Diameter of a Sphere or Cylinder.—It is impossible by means of a scale alone to measure the diameter of a sphere. With the assistance, however, of two blocks of wood, the ends of which are accurately squared off, this measurement can be made.

Lay the scale flat on the table, and place the two blocks of wood alongside the graduated edge with the sphere between them, in the manner shown in Fig. 4. Then take the readings on the scale opposite the ends of the two blocks. The difference between the readings will be the diameter of the sphere.

An inaccurate result will be obtained if the ends of the blocks are not at right angles to the sides. To test whether this is so, remove the sphere, and, placing the blocks in contact,

see if their ends touch all round. If they do not they are not square; and even if they do it does not follow that they are

FIG. 4.

square, for two blocks having the shape of those shown at A, Fig. 5, touch all round. If, however, one of the blocks be

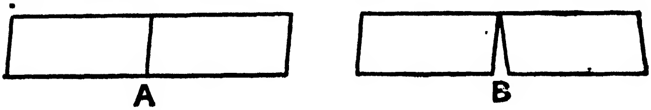


FIG. 5.

turned over, so that the face which was at the top is now next the table, then if the ends of the blocks are square they still touch all round; but if they are not square they no longer do so, as is shown at B.

EXERCISE 6.—*To measure the diameter of a sphere.*

Apparatus:—Two blocks of wood with accurately squared ends; metal or wooden sphere; scale.

Test whether the ends of the two blocks of wood supplied to you are square with the sides, entering in your note-book a description of the tests you apply, and the reasons why you apply them.

Then measure the diameter of the given sphere, also the longest and shortest diameters of an egg. Enter your results in a table similar to that employed in Exercise 3.

EXERCISE 7.—*The slide calipers.*

Apparatus:—Slide calipers; sphere, etc., used in previous exercise.

An instrument which works on the same principle as that employed in the previous exercise is shown in Fig. 6, and is called the slide calipers. The two metal jaws—one of which, A, is fixed to

the stem, and the other, B, is movable—take the place of the blocks of wood used in the last exercise, while the distance between the

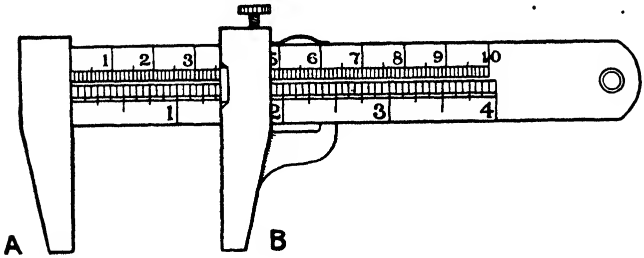


FIG. 6.

jaws can be directly read off by means of the scale engraved on the stem.

Repeat the measurement of the last exercise, using the slide calipers.

EXERCISE 8.—*To make a copy of a millimetre scale.*

Apparatus:—Piece of wood 24 in. × $\frac{1}{2}$ in. × $\frac{1}{2}$ in.; steel millimetre scale; pencil and pins; strip of cardboard.

At about an inch from one end of a piece of wood about two feet long and half an inch square, drive a stout blanket-pin right through the wood, so that the point projects about a quarter of an inch. At about the same distance from the other end, cut a deep notch in the wood parallel to the pin, and firmly tie a short length of blacklead pencil into this notch. Then fasten the millimetre scale and a strip of cardboard to the top of your table with drawing-pins, so that they are in the same straight line and about one foot apart. On the card draw two longitudinal lines, to show the lengths of the long and short division-lines respectively. Then, placing the point of the pin successively in each of the divisions of the steel scale, draw a corresponding division-line on the card, making the fifth and tenth lines longer than the others. Number the whole centimetre divisions.

The Wedge.—ABC, in Fig. 7, represents a triangle of which the side AB is 10 cm. long, and the side BC 1 cm., and the angle at B is a right angle. This triangle has been drawn on paper which is divided up into a number of squares by two sets of parallel straight lines at right angles to one another. The

straight lines in each set are exactly a millimetre apart, while, to facilitate counting, every tenth line is made a little darker. Thus the distance between each of the dark lines is 1 cm.,

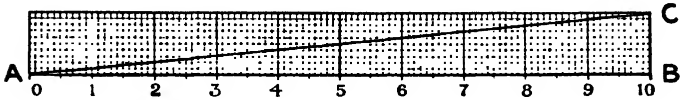


FIG. 7.

and the distance from A to B is 10 cm., the distance from B to C being 1 cm. Such paper, for a reason which will appear later on, is called *curve paper.*

We require to find if there is any constant relation between the height of any of the vertical lines intercepted between AB and AC and the distances of these lines from A measured along the horizontal line AB. In order to investigate this point we draw out a table giving the height at every whole centimetre from A to B. Thus :—

Distance from A	..	0	1	2	3	4	5	6	7	8	9	10 c.m.
Height	..	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0 c.m.

It will at once be seen that in each case there are as many millimetres in the height as there are centimetres in the distance from A. As there are 10 mm. in a centimetre, this means that the height at any point is one-tenth ($\frac{1}{10}$) of the distance of that point from A.

EXERCISE 9.—*The wedge.*

Test the truth of the above statement by noting to the nearest tenth of a millimetre the heights at the following distances from A :—4·3 cm. ; 7·8 cm. ; 5·5 cm. ; 9·0 cm. ; 8·55 cm.

Enter your results as in the following example :—

Distance from A.	$\frac{1}{10}$ of the Distance from A.	Measured Height.
2·6 cm.	0·26 cm.	0·26 cm.
7·2 „	0·72 „	0·72 „

EXERCISE 10.—*Use of the wedge to measure small lengths.*

Apparatus :—A triangular piece of curve paper, similar to Fig. 7, mounted on thin card; some short lengths of glass tube.

Insert the thin end of a wedge-shaped piece of cardboard which is divided in the same way as the triangle, Fig. 7, as far as it will go into the bore of a piece of glass tube, and note the reading on the side AB which is opposite the end of the tube. From this reading, the internal diameter of the tube can be immediately deduced, since the height of the wedge at the given point is known, from the previous exercise, to be a tenth of the distance of the given point from the end of the wedge. Record your results as in the following example:—

Length of wedge = 10 cm.
Height of wedge = 1 cm.
Reading on AB opposite end of tube = 4·32 cm.
∴ diameter of bore of tube = 0·432 cm.

The Screw.—The cylinder shown in Fig. 8 is exactly 10 cm. in circumference, and has a piece of curve paper pasted round it; and on this paper a series of lines, such as AC, Fig. 7, have been drawn. Now, if we start from the point B and follow the sloping line right round the cylinder, we shall, after making a complete turn, arrive at C. Hence, in travelling once *round* the cylinder, we have travelled down the cylinder through a distance, BC, which is 1 cm. If we go round another whole turn we shall, in the same way, arrive at D, the distance CD being equal to BC. If, however, instead of going a whole turn, we had originally only gone one-fifth (= 0·2) of a turn, how far down the cylinder should we have gone? Without actually measuring we can at once say, for, if we could unroll the paper from the cylinder, we should have a triangle exactly like the triangle ABC, Fig. 7, the edge of the paper corresponding to the side AB, while the slanting line

FIG. 8.

joining B and C would correspond to the side AC. Since the circumference of the cylinder is 10 cm., if we have gone 0·2 of a turn that means we must have gone 2 cm. along the circumference from B, that is, to E, and we know that the height of the wedge at 2 cm. from the point A is 2 mm. Hence, if we have gone 0·2 of a turn round the cylinder, we must have gone 2 mm. down the cylinder.

The slanting line which goes round and round the cylinder forms what is called a spiral line, or screw, on the surface of the cylinder.

EXERCISE 11.—*The screw.*

Apparatus:—A cylinder on which a screw has been traced.[1]

You are supplied with a cylinder similar to that shown in Fig. 8. Determine how far down the cylinder you will have gone after following the spiral line for 0·7, 1·3, 4·75 turns. From your results see if you can discover a simple rule, similar to that given with reference to the wedge on p. 11, by means of which, if you are given the number of turns, you can immediately write down the distance travelled parallel to the length of the cylinder.

The Screw and Nut.—Instead of keeping the cylinder fixed and following the spiral line round and round, we might have turned the cylinder, at the same time moving it parallel to its length, so that the spiral line always remained opposite some fixed point. In this case, by counting the number of turns and fractions of a turn, we could at once say how far the cylinder had moved parallel to its length. In order to facilitate this operation the spiral line might consist of a groove cut in the wood, and the fixed point might be a small peg attached to the table and fitting into this groove.

In the screw and nut we have an arrangement of this kind, the peg being replaced by the nut, which is equivalent to a

[1] A wooden cylinder 10 cm. in circumference (*i.e.* $1\frac{1}{4}$ inches in diameter), round which a piece of mm. curve paper, 10 cm. by 6 cm., has been pasted. Before sticking on the paper draw a series of straight lines dividing the paper into a number of triangles each equal to ABC, Fig 7, and so arranged that the lines, when the paper is wrapped round the cylinder, form a screw with a one-cm. pitch.

series of pegs fitted inside a collar so that they cannot slip out of the groove. The ridge between two neighbouring turns of the groove is called the thread of the screw, and the distance between the centres of two adjacent threads is called the pitch of the screw. Each time the screw is turned once round it will move through the nut a distance equal to the pitch of the screw.

EXERCISE 12.—*Screw and nut.*

Apparatus:—Screw and nut.

Determine the pitch of the screw supplied to you by measuring the distance between ten threads and dividing this distance by ten. Then prove, by measurement, that, when the nut is rotated through a complete turn, it travels down the screw through a distance equal to the pitch of the screw. Also find, by measurement and calculation, the distance which the nut travels along the screw in making 2·5, 4·3, and 8·75 turns respectively.

The Screw Gauge.—The screw is often employed when very small distances have to be accurately measured. An instrument called a screw-gauge, in which a screw is used for this purpose, is shown in Fig. 9. The object to be measured,

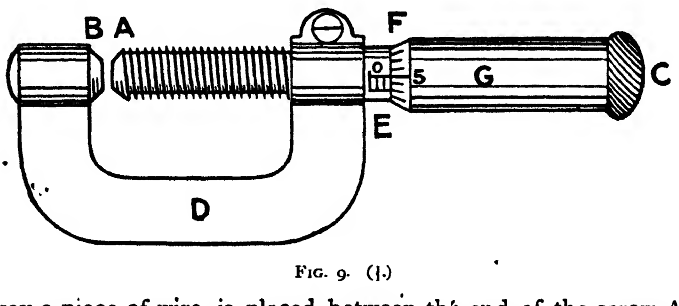


FIG. 9. (½.)

say a piece of wire, is placed between the end of the screw A and the block B, which is attached to the nut by the strong curved arm D. The screw can be turned by the milled head C, the number of *whole* turns being read off on the scale E, which is so divided that a complete turn of the screw moves the edge of the cap G, which is fixed to the screw, through the distance between one division-line and the next. The

fractions of a turn are read off on the scale F, engraved on the edge of the cap G. The pitch of the screw is generally 0·5 mm., and the edge of the cap is divided into 50 equal parts. Therefore, since turning the screw through a complete turn moves the end A through a distance of 0·5 mm., one division on the scale F corresponds to a motion of the screw point of $\frac{1}{50}$ of 0·5 mm., or 0·01 mm.

EXERCISE 13.—*The screw-gauge.*

Apparatus:—Screw-gauge; pieces of wire of various diameters.

Measure the diameters of the pieces of wire supplied to you by means of the screw-gauge.

When making a measurement with a screw-gauge hold the cap G very lightly between the thumb and first finger of the right hand, and turn the screw till the object is just *lightly* gripped between the end of the screw and the block B. If the instrument is screwed up tight against an object the screw thread will be injured, and the reading will be less likely to be correct than if only a light pressure is employed.

The Measurement of the Length of Curved Lines.—Hitherto we have only been considering the measurement of the length of the *straight* line joining two given points, we have next to consider the methods of measuring the length of curved lines.

A curved line such as AB, Fig. 10, may be considered as built up of a number of short straight lines placed end to end, as shown at CD. The length of the line will then be the sum of the lengths of all these short straight lines.

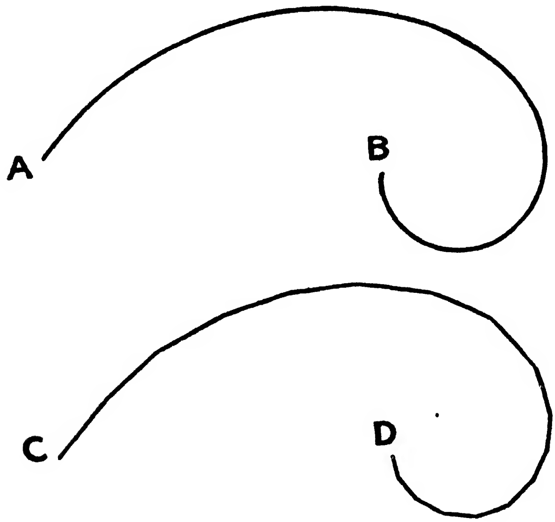
EXERCISE 14.—*The measurement of the length of a curved line by means of dividers.*

Apparatus:—A pair of dividers,[1] a pair of compasses with pencil-point.

If we make each of the small straight elements, into which we break up the curved line, of the same length, then by simply multiplying the length of each element by the number of elements we shall obtain the length of the line. In order to apply this method adjust the hair-dividers so that the distance between

[1] Spring-bows are somewhat easier to manage than dividers for this experiment.

the points is 3 mm. Place one point at the extremity A of the line, and turn the dividers till the other point rests on the line in direction of B. Then, keeping this point fixed, turn the dividers till the first point again rests on the line. Continue this stepping process till the other end of the line is reached, keeping count of the



number of steps taken. The total number of steps multiplied by the length of a step (3 mm.) will be the length of the line.

With a pair of compasses having a sharp pencil-point draw in your note-book a circle with a radius of about 4 cm. Measure the length of the diameter by means of a scale, and the length of the circumference by the above method.

EXERCISE 15.—*Measurement of curved lines with a fine thread.*

Apparatus :—Cotton ; a sheet of the one-inch ordnance map.

If it were possible to lay a piece of cotton exactly on the curved line which has to be measured, and to place marks on the cotton at the extremities of the line, then by stretching the cotton straight and measuring with a scale the distance between the two marks we should get the length of the line. Since, however, it would be

difficult to get the cotton to lie all along the whole length of the line at once, we have to adopt a slightly modified method. The manner of performing the experiment is shown in Fig. 11. Place one of the

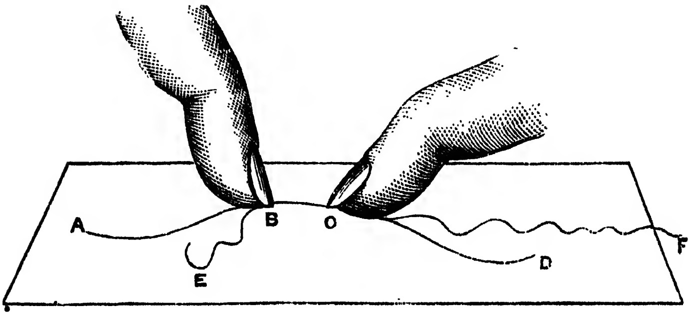


FIG. 11.

ends of the thread at one extremity of the given line; then, holding it there with the first finger of the left hand, stretch the thread along a short portion of the line, and hold it down with the nail of the first finger of the right hand. Now move the left finger up close to the right finger, and then stretch the thread over another short portion of the curve. Proceed in this way till the end of the line is reached. The length of thread used must then be measured by means of a scale.

Measure by this method the circumference of the circle used in the previous exercise. Also measure the distance from —— to —— along the road marked on the ordnance map, and, given that an inch on the map represents a mile, express the distance in miles.

EXERCISE 16.—*To find the number of times the diameter of a circle is contained in the circumference.*

Apparatus:—Wooden discs of various diameters—4 in., 6 in., 8 in., and about 1 in. thick; strips of thin paper; scale.

Wrap a strip of thin paper *tightly* round the edge of one of the wooden discs supplied to you, so that the ends overlap for about half an inch. Then, at a place where the two ends of the strip overlap, prick a small hole through the paper with the point of a pin. Having unrolled the paper, carefully measure the distance between the two pin-holes by means of a scale. This length will be the circumference of the circle formed by either edge of the disc. On the

surface of the disc, and through the centre,[1] draw four diameters so as to divide the circle into eight nearly equal sectors.

Measure the length of each of the four diameters, and take the mean (see p. 6). Now divide the number expressing the length of the circumference by the number expressing the length of the diameter, continuing the division to the third place of decimals. Be careful to measure the circumference and the diameter in the same units, thus either measure both in centimetres or both in inches.

Repeat the measurements, using discs of two other sizes; and then draw up a table, as in the following example:—

Mean Diameter.	Circumference.	$\frac{\text{Circumference}}{\text{Diameter}}$
10·16 cm.	31·96 cm.	3·146
15·26 ,,	47·92 ,,	3·140
21·20 ,,	66·55 ,,	3·139

If you have made your measurements carefully you will find that, although the sizes of the circles you have measured are very different, the numbers you obtain in the last column are nearly the same. This shows that, as nearly as you are able to tell, the number obtained by dividing the length of the diameter into the length of the circumference is the same for *all* circles, or, more shortly, the ratio of the length of the circumference of a circle to the length of the diameter is constant.

The Value of π.—It can be proved by geometry that the ratio of the length of the circumference to that of the diameter is exactly the same for *all* circles. This ratio is generally indicated by the Greek letter π (*pi*), and is equal to 3·1416 . . . For all practical purposes it is sufficiently near if the more easily remembered fraction $3\frac{1}{7}$ or $\frac{22}{7}$ is taken as the value of π.

Knowing the value of π, we can, if we are given the diameter of a circle, calculate the circumference, or, if we are given the circumference, calculate the diameter. As an example,

[1] If the centre of the face of the disc is not marked, draw any straight line right across the face, bisect this line by means of the dividers, and through the point of bisection, by means of a set square, draw a chord at right angles to the first line. Bisect the chord; this point will be the centre of the circle.

suppose the diameter of a circle is 4·3 cm., what is the circumference?

$$\text{Since} \qquad \frac{\text{circumference}}{\text{diameter}} = \pi = \frac{22}{7}$$

$$\therefore \frac{\text{circumference}}{4{\cdot}3} = \frac{22}{7}$$

$$\therefore \text{circumference} = \frac{22}{7} \times 4{\cdot}3 = 13{\cdot}514 \text{ cm.}$$

Again, if the circumference of a circle is 10 cm., what is the diameter?

$$\text{Here} \qquad \frac{10}{\text{diameter}} = \frac{22}{7}$$

$$\therefore \text{diameter} = 10 \times \frac{7}{22} = 3{\cdot}182 \text{ cm.}$$

EXERCISE 17.—*Calculation of the diameter or circumference of a circle.*

(*a*) Calculate the circumference of a circle having a diameter of 8·3 cm., and also of a circle of which the *radius* is 5·2 cm.

(*b*) Calculate the diameter of a circle of which the circumference is 50 cm.

SECTION II.—THE MEASUREMENT OF MASS.

All bodies which we are able to detect by means of our senses, such as wood, stone, air, water, etc., may be supposed to consist of matter, so that any given portion of any of these substances will contain a certain definite quantity of matter. The quantity of matter in a body is called its MASS.

We are not able to compare masses as we do lengths by simply placing them alongside one another, since we are unable to judge by eye alone when two masses are equal. Hence an indirect method has to be employed for comparing the mass of two bodies.

The most usual method is to make use of the fact that the pull or force with which the earth attracts a body at any place depends only on the mass of the body, so that if the pulls exerted on two bodies by the earth are found to be equal, we know that their masses are also equal. This pull which the

earth exerts on a body is called the *weight* of the body. Hence it is very common to speak of the weight of a body when really the mass is what is meant. It is also usual to refer to the operation of determining the mass of a body as *weighing*. It is important to clearly understand the difference between weight and mass. If a body, say a lump of lead, is taken up in a balloon, the pull exerted by the earth on the lead—that is, the *weight*[1] of the lead, steadily diminishes as the balloon rises. The amount of matter in the lump of lead, however, would not alter, as none of the lead would have been lost, and therefore the *mass* would still remain the same although the weight had altered. The mass of a body cannot alter unless some of the matter of which it is composed is taken away, or fresh matter added. The weight, however, may alter if the body is simply carried from one place to another, since the force with which the earth attracts a given mass varies from place to place even on the surface of the earth.

The British unit of mass is a certain lump of platinum which is preserved at Westminster together with the standard yard, and is called the POUND AVOIRDUPOIS. The following table gives some of the more commonly used multiples and subdivisions of the pound.

437·5 grains	=	1 ounce (oz.)
16 ounces	=	1 pound (lb.)
14 pounds	=	1 stone.
112 pounds	=	1 hundredweight (cwt.)
20 hundredweight	=	1 ton.

Here, as in the case of the units of length, no regular system has been employed, and to convert from one unit to another we have to multiply or divide, as the case may be, by 14, 112, 20, etc.

The metric unit of mass is also a certain lump of platinum which is preserved at Paris, and is called the KILOGRAMME. The kilogramme is equal to about 2·2 lbs.

[1] The pull exerted by the earth may be measured by a spring balance, an ordinary balance would not do, as the pull exerted on the "weights" would also decrease.

The subdivisions of the kilogramme are decimal, and are given in the following table:—

10 milligrammes	=	1 centigramme.
10 centigrammes	=	1 decigramme.
10 decigrammes	=	1 gramme (grm.).
1000 grammes	=	1 kilogramme (kilo.).

The advantage of the metric system over the British system is well shown if, say, we require to reduce (1) 81453 ozs. to tons, and (2) 16785 decigrammes to kilogrammes.

The steps in the reduction are as follows:—

(1)	16)81453	(2)	16785 decigrammes.
	112)5090 + 13 ozs.		1678·5 grms.
	20)45 + 50 lbs.		1·6785 kilos.
	2 + 5 cwt.		
	Ans. 2 tons 5 cwt. 50 lbs. 13 ozs.		Ans. 1·6785 kilos.

In the one case we have to divide by 16, then by 112 and 20; while in the other we have simply to move the decimal point.

The Balance.—The most usual method of comparing the pulls exerted by the earth on two bodies, and thereby comparing their masses, is by means of the balance, or scales. A form of balance suitable for comparing such masses as will be required in this course is shown in Fig 12.[1] The beam of the balance, together with the stirrups carrying the scale-pans, can be raised by turning the lever A to the right. When the balance is not in use, and whenever *anything* has to be placed in or removed from the pans, the lever A must be turned as far as possible to the left, so that the pans rest on the stand. A long pointer attached to the beam, and moving in front of an ivory scale B, enables us to see when the loads in the two pans are equal. The beam is supported by a steel knife edge, which rests on two small flat steel plates fixed to the top of the pillar. The pans are suspended from small stirrups, which are fitted with slightly curved steel plates. These plates rest on knife

[1] It will be found of great assistance if the teacher takes one of the balances to pieces, and shows the construction of the different parts to the pupils, allowing them to examine each part.

edges which are fixed to the end of the beam. An enlarged view of the end of the beam and the stirrup is shown in Fig. 13. The small weight E can be screwed nearer or further away from the middle of the beam, and is used to adjust the balance

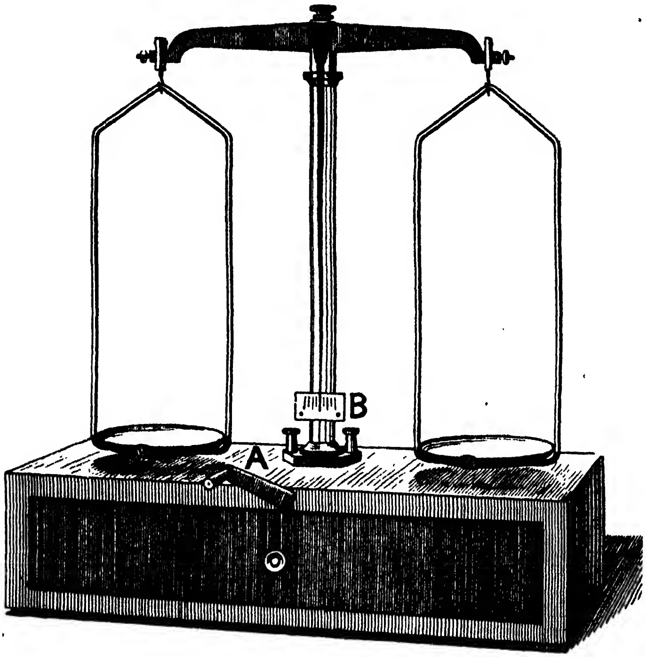


FIG. 12. (⅛.)

of the beam so that when both pans are empty the pointer is at the centre of the ivory scale.

When using a balance it is important to observe the following rules, or much time will be wasted, and the balance and weights quickly ruined.

I. Nothing must be placed on or removed from the pans, nor must the moving parts of the balance be in any way touched, unless the pans are resting on the base of the balance.

II. Never, on any account, use the balance for comparing greater masses than it is intended to carry. Hence, before starting to use a balance, ascertain the maximum load which may be employed.

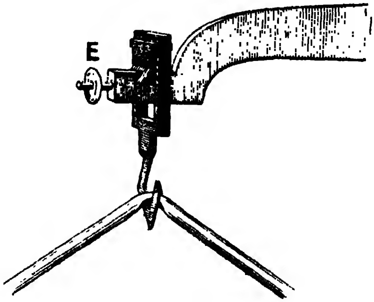


FIG. 13.

III. Before starting to weigh a body, raise the beam and see that it swings regularly. Note the position of rest of the pointer, and in the subsequent weighings take this position as the zero to which the pointer has to be brought back. It is not necessary to wait till the beam comes to rest, but note whether the pointer swings over the same number of divisions of the scale on each side of the zero.

IV. Place the body to be weighed in the left-hand pan and the weights in the right-hand pan, since in this position the arrester can be worked with the left hand and the weights changed with the right.

V. Raise the beam slowly, and if the pointer immediately and decidedly indicates which side is the heavier, lower the beam again, and alter the weights in the direction indicated. Only when the equality of the loads in the two pans is nearly reached need the beam be entirely raised.

VI. Till some experience in judging the mass of a body has been obtained, try all the weights in order, without omitting any, commencing with the largest.

VII. Never touch the weights with your fingers; use the tweezers supplied for this purpose.

VIII. Place the box of weights as near the right-hand pan as is convenient, so that if by accident a weight slips out of the tweezers there is no chance of its falling on the floor. The weights should never be placed anywhere except on the pan of the balance or in their proper place in the box.

When the fractions of the gramme are not placed in separate subdivisions in the box, rule and number a small piece of card-board in the manner shown in Fig. 14. Place this card on the base-board of the balance, and on it arrange the fractions of a gramme, replacing each weight on its proper square after use.

·5	·2	·1	·1
·05	·02	·01	·01

FIG. 14. (½.)

IX. When equilibrium has been obtained, read the mass by seeing what weights are missing from the box. Then make a note of the value of each weight as you replace it in the box, and see that the value thus obtained agrees with that previously got by reading the weights missing from the box.

EXERCISE 18.—*Determination of mass by means of the balance.*

Apparatus:—Balance; set of weights 50 grms. to 0·01 grm.; pieces of metal (coins).

Determine the mass, in grammes, of the given pieces of metal; also of a penny.

EXERCISE 19.—*Comparison of British and metric units of mass.*

Apparatus:—Balance and weights used in previous exercise, also common scales capable of weighing up to 3 lbs.; gramme weights up to 1 kilo.; British weights 1 oz. to 2 lbs.

Determine by means of the scales the number of pounds and ounces in a kilogramme. Also the number of grammes in a pound.

On the sensitive balance determine as accurately as possible the number of grammes in an ounce, and from your results fill in the following table:—

1 kilogramme	=	.... lbs. .... oz.
1 gramme	=	.... oz.
1 pound	=	.... grms.
1 ounce	=	.... grms.

SECTION III.—THE MEASUREMENT OF AREA.

The unit of *area*, or *surface*, that is usually employed is the area of a *square* each side of which is of unit length. Thus, in the metric system, a square each side of which is one centimetre may be taken as the unit of area, and is called a *square centimetre*, sometimes written cm^2. In the same way, we have the British units of area—a square inch, a square foot, etc.

Suppose we have a square each side of which is 1 decimetre 10 cm.) long, and that divide two adjacent sides into centimetres, and through these points draw lines parallel to the sides of the square, as in Fig. 15, then the square will be divided up into a number of small squares. The area of each of these small squares will be 1 sq. cm., since the sides of each are 1 cm. long. Taking the small squares in horizontal rows, it will be seen that each row contains ten squares, and that there are ten rows. Hence there are 10×10, or 100 squares in all; that is, there are 100 sq. cm. in 1 sq. decimetre.

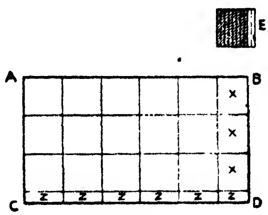


FIG. 16.

Suppose the area to be measured is a rectangle, the length being 5·8 cm., and the breadth 3·3 cm. Then if, as before, two adjacent sides, AB, AC, Fig. 16, are divided into centimetres, starting in each case from A, and lines parallel to the sides are drawn through these points, fifteen small squares, each 1 sq. cm. in area, and nine small rectangles, each of

which is less than 1 sq. cm. in area, will be formed. Of these small rectangles those marked × are 1 cm. broad and 0·8 cm. long. If a square centimetre is divided into ten equal strips, as at E, Fig. 16, then the shaded part will be equal to one of the above rectangles, and it is obvious that the area of the shaded part is eight-tenths (0·8) of a square centimetre. Hence the area of each row in the rectangle is 5·8 sq. cm. If one of these rows was divided into ten equal strips, each 0·1 cm. wide, then the area of the rectangles marked Z in Fig. 16, would be equal to three of these strips. Thus the area of the rectangles Z is three-tenths of 5·8 sq. cm. The total area of the rectangle is, therefore, 3·3 times the area of one of the rows; that is, 3·3 × 5·8 sq. cm. = 19·14 sq. cm. It will be seen that we obtain the area of the rectangle by multiplying the lengths of two adjacent sides (AB, AC) together. This is always true, and the area of any rectangle can be obtained by multiplying together the numbers which represent the lengths of two adjacent sides. If the lengths of the sides are measured in centimetres, the area will be expressed in square centimetres; if the sides are measured in inches, the area will be expressed in square inches, etc.

EXERCISE 20.—*Area of rectangular figures.*

Apparatus :—Metre and yard scales.

Measure the area of the top of your work-table and of a page of your note-book, both in square centimetres and in square inches. Enter your results as in the following example :—

Length of Table.	Width of Table.	Area.
122·3 cm.	76·1 cm.	9307·03 sq. cm.

EXERCISE 21.—*The measurement of the area of figures other than rectangles.*

Apparatus :—Curve paper ; compasses with pencil-point.

The area of any figure can be obtained in a manner resembling that employed when measuring the length of a curved line (Exercise 14). Suppose the given figure divided up into a number of small

equal squares, by means of two sets of parallel lines drawn at right angles to one another. Then, if we count the number of these small squares within the figure, and multiply by the area of one of these squares, the product will give us the area of the figure.

In order to save the time necessary to draw a large number of parallel lines, the given figure (Fig. 17) may be drawn on curve paper (see p. 11). It will not be necessary to count the small squares in any of the large squares (formed by the tenth lines, which are ruled darker than the others) that are not cut by the boundary of the figure, because each of these large squares contains 100 small squares. Thus, first count the number of small squares within the figure in those large squares through which the boundary passes, then to this number add as many hundreds as there are whole large squares within the figure. The area will in this way be obtained in square millimetres, since each of the small squares has an area of 1 sq. mm. If necessary, this value can be reduced to square centimetres by dividing by 100. If the boundary line cuts through a small square it is generally sufficiently accurate if we count the square when more than half is within the figure, and omit it when less than half is within the figure.

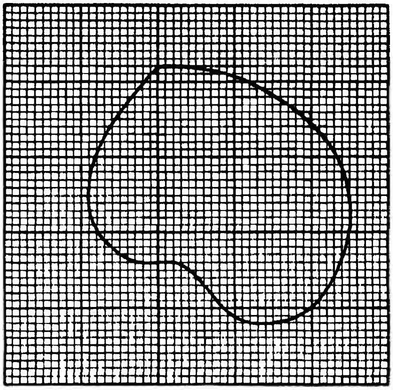


FIG. 17.

Determine by this method the area of a circle 6 cm. in diameter.

EXERCISE 22.—*Measurement of area by the method of weighing.*

Apparatus:—Balance; thin cardboard; tracing paper; scissors; map.

Another method of measuring the area of plain figures is to cut out the figure from a sheet of cardboard, or some other material of uniform thickness, and weigh it. Then, if we know the number of square centimetres of the cardboard which weigh a gramme, we can calculate the area of the figure. To get the number of square

centimetres in a gramme, cut the piece of card given you into a rectangle, the larger the better, and weigh it. Calculate the area from the length and breadth of the rectangle, and divide the number of square centimetres in the area by the weight in grammes; the quotient will be the number of square centimetres which weigh a gramme.

Draw a circle on the card, by means of a pair of compasses, with 6 cm. radius. Carefully cut out this circle, and weigh it. The weight multiplied by the number of square centimetres of the card-board which weigh a gramme will be the area of the circle in square centimetres.

Trace on tracing-paper the outline of the county of —— from the map supplied to you, paste this tracing on to cardboard, and determine by the above method the area in square miles.

EXERCISE 23.—*Relation between the area of a circle and the diameter.*

It can be shown from geometry that the area of a circle of radius r is πr^2, where π represents the ratio of the circumference of a circle to its diameter.

Calculate by this expression the area of the circles measured in the two previous exercises, and draw up a table as follows :—

Radius of Circle $= r$.	Calculated Area $= \pi r^2$.	Measured Area.

Area of a Parallelogram.—A parallelogram is a quadrilateral figure in which the opposite sides are parallel. The figure ABCD, Fig. 18, is a parallelogram because the side AB is parallel to the side DC, and the side AD is parallel to the side BC. If the side AB is produced to M, and then from C and D straight lines are drawn perpendicular to MB, then FECD is a rectangle. Since the triangle FDA is equal to the triangle ECB, if we cut off the triangle ECB from the parallelogram ABCD, this part cut off would exactly fill up the triangle FDA, and we should convert the parallelogram ABCD into the rectangle FECD without altering the area. Therefore,

in order to determine the area of the parallelogram, we have only to measure the area of the rectangle FECD. But the area of this rectangle is obtained by multiplying the base DC

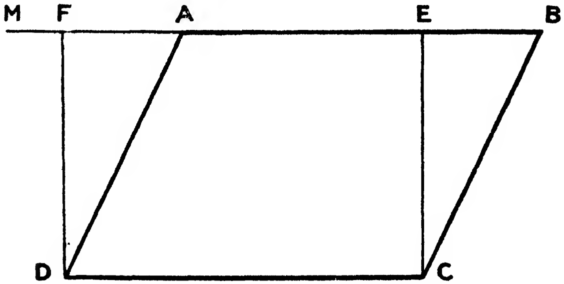


FIG. 18.

by the height CE (p. 26). Thus the area of a parallelogram is equal to the product of the base (DC) into the perpendicular distance between the base and the opposite side (CE or FD).

EXERCISE 24.—*Area of a parallelogram.*

Apparatus :—Parallel rule ; paper ; scissors ; millimetre scale.

Draw on a sheet of paper a parallelogram similar to ABCD, Fig. 18, having the sides AB and DC about 4 inches long, and the sides AD and BC about 3 inches long. Also draw the rectangle FECD, which has the same area as the parallelogram. Then carefully cut out the triangle EBC and prove by actual superposition that it is equal to the triangle FDA.

Measure the lengths of DC and FD, and calculate the area of the rectangle, and thus obtain the area of the parallelogram.

Also draw a straight line from C perpendicular to AD, and, by measuring the length of this perpendicular and the length of the side AD, obtain a second value for the area of the parallelogram ABCD.

Area of a Triangle.—If in the triangle ABC, Fig. 19, we draw AE parallel to BC, and CE parallel to BA, then the figure AECB is a parallelogram, and the area of this parallelogram is twice that of the triangle ABC, because the triangle AEC is equal to the triangle ABC. But the area of

the parallelogram AECB is obtained by multiplying BC by AD. Hence the area of the triangle ABC is equal to half

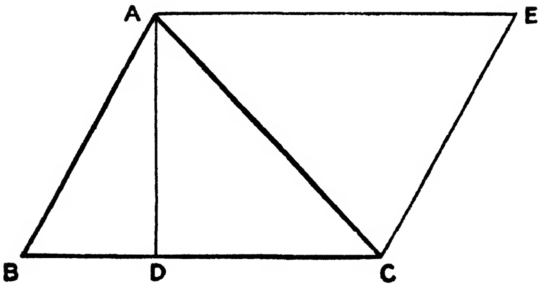


FIG. 19.

the product of BC and AD—that is, half the product of the base into the height.

EXERCISE 25.—*Area of a triangle.*

Apparatus :—As in previous exercise.

Draw on a large scale a figure similar to Fig. 19, and prove by cutting out the triangle that ACE is equal to ABC.

Also measure BC and AD, and calculate the area of the triangle.

Repeat the measurement, taking the sides AB and AC in turn as the base, and the perpendiculars from C and A respectively as the height.

SECTION IV.—THE MEASUREMENT OF VOLUME.

Just as in the case of area the unit employed is a square each side of which is of unit length, so for all scientific purposes the unit of volume is the volume of a *cube* each edge of which is of unit length, and therefore each face of unit area. There are certain British units of volume, such as the pint, gallon, etc., which have no simple relation to the units of length; the use of such units, however, often leads to great complications.

The unit of volume used commercially on the Continent is the litre, and is the volume of a cube each edge of which is a decimetre. In these exercises we shall generally employ the

volume of a cube each edge of which is a centimetre, as the unit of volume. This unit is called a cubic centimetre, and is denoted by c.c. or cm^3.

Volume of a Right Prism.—The volume of any body in the form of a right prism [1] can be obtained by multiplying the number of units of area in the base into the number of units of length in the height.

The truth of the above rule will be evident after what has been said on p. 25. For the number of units of area in the base represents the number of unit cubes which can stand on the

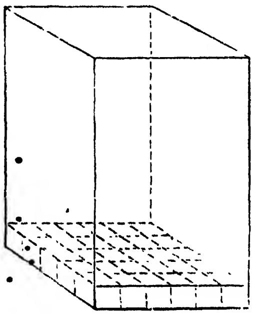


FIG. 20.

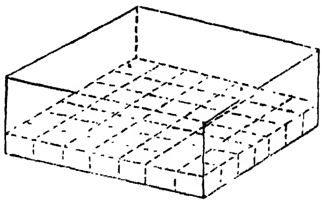


FIG. 21.

base, since the face of each unit cube is of unit area. Hence, if the prism is divided into horizontal slices, each slice being unit length in thickness, there will be as many slices as there are units of length in the height of the prism. Therefore the total volume will be the number of units of area in the base multiplied by the number of slices—that is, by the number of units of length in the height. Figs. 20, 21, 22, and 23, show several right prisms.

EXERCISE 26.—*Determination of volume by measurement.*

Apparatus:—Right prisms, in wood or metal, on rectangular, triangular, and circular bases; millimetre scale; slide calipers.

Measure the length and breadth of one face of the rectangular prism supplied to you, and hence calculate the area of the face.

[1] A right prism is a body of which the ends are parallel and the sides are everywhere at right angles to the ends.

Then measure the length of the edges perpendicular to this face, to get the height. Calculate the volume of the prism by multiplying the area of the base by the height.

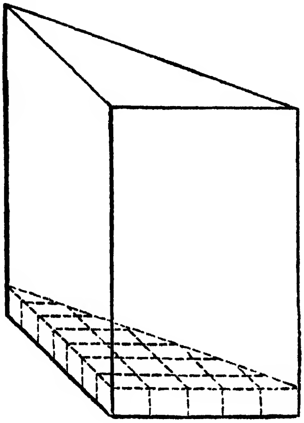


FIG. 22.

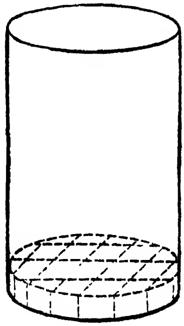


FIG. 23.

Measure the diameter of the cylinder supplied to you by means of the slide calipers, and then calculate the area of the end by the formula—

$$\text{Area of a circle} = \pi r^2,$$

where r is the radius. Also measure the length of the cylinder, and calculate the volume.

Measure the area of the end of the triangular prism supplied to you by the method of Exercise 25, also measure the height, and hence calculate the volume.

Calculate the number of cubic centimetres in a litre.

Connection between the Units of Mass and Volume in the Metric System.—The unit of mass in the metric system (the kilo.) was chosen as being the mass of a litre of water at a temperature a little above the freezing point of water. Since there are 1000 c.c. in a litre and also 1000 grms. in a kilo., a c.c. of water weighs a gramme.[1] This connection between the units of mass and volume in the

[1] It is only at a temperature of 4° C. that a c.c. of water weighs exactly a gramme. The effect of temperature on the volume of water will be considered later.

metric system will be found of great service, for by simply weighing a given quantity of water we can immediately write down its volume.

EXERCISE 27.—*The connection between the units of mass and of volume in the metric system.*

Apparatus:—Cubical tin box to hold a litre; pint measure; scales and weights.

Determine the volume of the inside of the cubical box supplied to you, by measuring the area of the open end and the depth. Then find the weight of water which fills the box, and thus verify the above statement as to the weight of a cubic centimetre of water. Also determine the weight of a pint of water, both in British and metric units. Hence calculate the number of cubic centimetres in a pint, and the number of pints in a litre.

In carrying out the above experiments, place the empty box or an empty glass beaker on the left-hand pan of the scales, and counterbalance by adding small shot to the right-hand pan. Then pour in the water, and, leaving the shot in the pan, add weights till equilibrium is again reached. Since the shot counterbalance the box or beaker, the added weights must give the mass of the water only.

FLUID MEASURES.

In order to measure the volume of fluids, variously shaped vessels are used. Some of the more usual forms are shown in Fig. 24. Of these, A is called a graduated cylinder, and is used for measuring a considerable volume of fluid, and where the volume is only required to the nearest whole cubic centimetre. A series of graduations on the side show either the volume between any given division and the bottom of the cylinder, or the volume between the division and a zero division near the top of the measure.

For measuring out a given volume of liquid with greater accuracy than is possible with the above, the arrangement shown at B, and called a burette, is used. It consists of a very narrow cylinder, graduated generally in tenths of a cubic centimetre, and fitted with a tap or pinch-cock, by means of which the liquid in the burette may be run off. Burettes are

generally graduated to read downwards, *i.e.* to give the volume of liquid run off. When a liquid is placed in the burette it

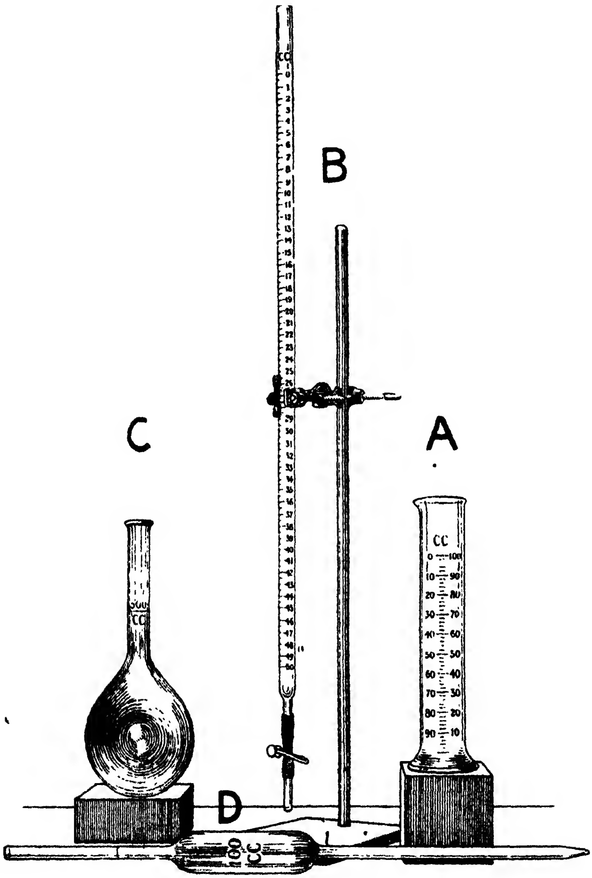


FIG. 24.

will be found that the surface is curved; it is best to read the graduation opposite the lowest part of the curved portion.

The flask C has a mark on the neck, and, when filled up to this mark, contains 500 c.c.

At D is shown a pipette, an instrument which also has a mark on the neck, and, when filled up to this mark, contains 100 c.c. The pipette is very useful when we wish to add or take away a small quantity of liquid from a vessel.

EXERCISE 28.—*Measurement of volume by means of fluid measure.*

Apparatus:—Graduated cylinders in British and metric measure; bottle; scales.

Measure the volume, in British and metric units, of a given bottle by determining the volume of water the bottle will hold, by means of a graduated cylinder; check your result by weighing the volume of water that fills the bottle (see Exercise 26).

EXERCISE 29.—*Determination of the volume of a solid by the displacement of water.*

Apparatus:—Graduated cylinder; pebble.

Select a pebble that will go into the graduated cylinder, and having taken the reading for the surface of the water, place the pebble in the cylinder. In order to prevent any chance of breaking the cylinder, tilt it and slide the pebble down one side. Again take the reading for the surface of the water. When the pebble is in the cylinder a certain space, which was before occupied by the water, is now occupied by the pebble, and therefore the surface of the water has risen in the cylinder. The apparent increase in the volume of the water is equal to the volume of the pebble. Thus the difference in the readings on the cylinder before and after the introduction of the pebble gives its volume.

By this method the volume of an irregular body can be obtained where it would be impossible to obtain the volume by direct measurement.

SECTION V.—THE MEASUREMENT OF DENSITY.

We have seen in the previous pages that all bodies with which we are acquainted have two properties in common; they all have mass and volume. We have now to consider these two properties in relation to one another. You are given two cubes, of the same material but of different sizes. Measure the volume and mass of each, and hence calculate the

mass of a cubic centimetre by dividing the number of grammes in the mass by the number of cubic centimetres in the volume.

It will be found that the mass of a cubic centimetre is the same for the two cubes. Repeat the measurements on a cube of some other material. The number now obtained for the mass of a cubic centimetre will be different; showing that while with bodies of the same material the mass of a cubic centimetre is constant, with bodies of different material the mass of a cubic centimetre varies. The mass of a unit of volume of any substance is called its DENSITY.

Since the mass of 1 cubic centimetre of water is 1 gramme, the density of water is unity.

EXERCISE 30.—*Measurement of density of fluids by weighing a known volume.*

Apparatus:—Balance; burette; beaker; methylated spirit; milk.

We may determine the density of fluids either by measuring the mass and the volume of a given quantity; or by measuring the mass of a certain volume of the fluid and then determining the volume by measuring the mass of an equal volume of water, since we know that the volume of 1 gramme of water is 1 c.c. In order to carry out a determination by the first method, place a small beaker on the left-hand pan of the balance, and carefully counterpoise with shot and tinfoil. Fill the burette with the given liquid, and note the reading for the surface of the liquid. Then run about 20 c.c. of the liquid into the beaker, again reading the burette. The difference between the burette readings will give the volume of the liquid. Replace the beaker on the balance, and add weights till equilibrium is reached. The mass of the added weights will be the mass of the volume of liquid taken. Divide the number of grammes in the mass by the number of cubic centimetres in the volume, and the quotient will be the mass of 1 c.c., *i.e.* the density. Measure by this method the density of methylated spirit and of milk, entering your results as in the following example:—

Reading of burette before running off liquid	=	5·4 c.c.
„ after „	=	26·2 c.c.
∴ Volume of liquid taken	=	20·8 c.c.

Mass of liquid = 21·42 grms.

$$\therefore \text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{21{\cdot}42}{20{\cdot}8} = 1{\cdot}03.$$

Density of a Liquid by Means of a Flask.—When the density of a liquid is to be measured by determining the mass of a certain volume, and when this volume is to be obtained by weighing an equal volume of water, it is necessary to be able to accurately obtain equal volumes of the given liquid and of water.

FIG. 25.

For this purpose a vessel of some kind must be employed, on the side of which a mark has been made to indicate to what level it has to be filled. In Fig. 25, A and B show two forms of vessel which might be used for this purpose. Now, when adjusting the level of the liquid to the mark, it is impossible to avoid slight errors in the level, and, on reference to the figure, it will be evident that the possible error in the volume of liquid taken is much greater in the case of a vessel such as A than in the case of one like B; for the volume of the shaded part of the liquid in A is very much greater than in B, although the depth of the shaded part, which represents the error that may be made in adjusting the level, is the same in the two cases.

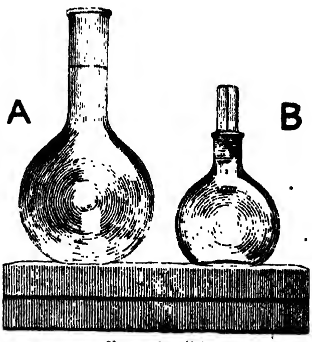


FIG. 26. (¼.)

Hence the narrower the neck of the vessel employed the better. For very accurate measurements a flask, fitted with a glass stopper through which a fine hole has been bored (B, Fig. 26), is employed. The flask is filled with the liquid, and the stopper is inserted; the superfluous liquid flows out through the hole in the stopper,

and is wiped off flush with the top. Flasks such as A and B are called specific-gravity or density bottles.

EXERCISE 31.—*Density of liquid by means of a flask.*

Apparatus:—Balance; narrow-necked flask with mark on neck; methylated spirit; milk, etc.

Counterpoise an empty and *dry* narrow-necked flask with shot and tinfoil, then fill it with water up to a mark on the narrowest part of the neck, replace on the balance, and add weights to the right-hand pan till equilibrium is restored. The mass of the weights added will be the mass of the water. From the mass of the water the volume of the flask up to the mark on the neck is at once obtained, since a gramme of water occupies 1 c.c.

Empty the flask, and carefully dry it by gently warming it over a Bunsen flame, and *sucking* out the air through a piece of glass tube. Fill with the given liquid up to the mark, and weigh. The shot and tinfoil used to counterbalance the flask when empty must be left on the right-hand pan while weighing the flask when full of the liquid. Then the mass of the weights added will be the mass of the liquid in the flask. Thus, knowing the mass and volume of the liquid, the density can be calculated.

Determine by this method the density of milk and of methylated spirit, entering your results as in the following example:—

Mass of water filling flask = 83·54 grms.

∴ Volume of flask up to mark = 83·54 c.c.

Mass of milk filling flask = 85·63 grms.

$$\text{Density of milk} = \frac{\text{mass}}{\text{volume}} = \frac{85{\cdot}63}{83{\cdot}54} = 1{\cdot}025.$$

ADDITIONAL EXERCISES IN MENSURATION.

1. Measure the circumference of a cylinder by wrapping ten or more turns of fine wire or cotton round the cylinder, then straightening out the wire and measuring the length. The wire must be wound on regularly, and in a *single layer*.

2. Measure the diameter of some wire by wrapping a number of turns of the wire in a single layer round a pencil, and measuring the length occupied by these turns. Each turn must lie in close contact with the neighbouring ones.

3. Test the accuracy of a set of gramme weights by balancing

the 50-grm. weight against all the rest, the two 20-grm. weights against each other, one of the 20-grm. weights against the 10, 5, 2, 2, and 1-grm. weights, and so on.

4. Determine the mass of 10 cm. of fine wire, and calculate the length of wire which will have a mass of 0·01 grm. Cut off a piece of wire rather larger than this, and adjust it exactly to 0·01 grm. by careful cutting.

5. Draw two parallelograms (not rectangles), each of which has an area of one square inch.

6. Find the area of a given polygon by dividing it into a number of triangles, and measuring the area of each of these triangles.

7. Find the volume of the slab of wood forming the top of your table, and, given that the density of the wood is ——, calculate the mass.

8. Find the area of cross-section of the bore of a graduated cylinder and of a burette, by measuring the length occupied by a given number of cubic centimetres.

9. Find the area of cross-section of the bore of the given test-tube by measuring with a burette, or by weighing the volume of water between two marks on the side about 10 cm. apart. How do you avoid the difficulty due to the closed end of the test-tube being curved?

PART II.—HYDROSTATICS.

Pressure Due to a Head of Liquid.—If a hole is bored through the bottom or side of a vessel containing a liquid, say water, then, so long as the hole is below the surface of the liquid, it is well known that the liquid will gush out. If an attempt is made to stop the flow of the water by closing the hole with the finger, the liquid will be felt pressing the finger. It is thus evident that the liquid presses, or exerts a pressure, on the inside of the containing vessel. In the same way, if a solid body is immersed in a liquid the liquid exerts a pressure on the outside of the solid. If the solid were removed and its place taken by the liquid, then this replacing liquid would be acted on by the same pressure, due to surrounding liquid, as was the solid. Hence, at any point below the free surface of a liquid there exists a pressure due to the liquid. This pressure is found to be proportional to the depth of the given point below the free surface of the liquid, or to the head of liquid, as it is called, and to the density of the liquid. Hence, if we know the head of liquid at any point, and also the density, then we can immediately calculate the pressure due to the liquid at this point.

EXERCISE 32.—*Balancing columns* (*manometer*).

Apparatus:—U-tube on stand : millimetre scale.

Pour water down one of the limbs of the U-tube till the two limbs are about a quarter full. Then measure the height of the surface of the water in the two limbs above the upper surface of the stand. Pour more water into the tube till both limbs are about one-third full, and again measure the height of the surfaces of the water above the stand. If the tube is clean it will be found that in

each case the surfaces of the liquid in the two tubes are at the same level.

Attach a short length of india-rubber tubing to the end of one of the limbs of the U-tube. Over this rubber tube slip a pinch-cock. Now gently blow down the rubber tube, opening the pinch-cock at the same time, till the surface of the water in one tube is about 6 or 8 inches higher than in the other, then shut the pinch-cock and measure the height of the surfaces of the water from the stand. The difference in the two heights will give the difference in level between the water in the two branches. In one limb, that exposed to the open air, the surface of the water is free, while in the other limb a pressure is exerted on the surface due to the air blown into this limb of the tube. At this surface the upward pressure, due to the head of water which now exists, exactly balances the downward pressure due to the air blown into the closed limb. Thus the difference in level in the two limbs is a measure of the pressure of the air in the closed limb. This pressure is therefore said to be equal to that exerted by a head of water equal to the difference between the level of the surfaces of the water in the two limbs. The U-tube and liquid, when used in this manner to measure pressures, is called a manometer.

Attach the rubber tube to the gas supply, and thus determine the height of the column of water which exerts the same pressure as that at which the gas is supplied.

Take a clean and dry U-tube, and, using mercury in the place of water, measure the height of the mercury column which exerts the same pressure as (1) the water supply,[1] and (2) the greatest pressure you can exert with your lungs.

EXERCISE 33.—*Comparison of the densities of two liquids which do not mix by the method of balancing columns.*

Apparatus :—U-tube on stand ; millimetre scale ; supply of various liquids, such as turpentine, paraffin oil, etc.

Pour water down one limb of the U-tube till both limbs are about one-third full, then carefully pour turpentine down the other limb. Go on adding turpentine till the surface of separation (B, Fig. 27) between the turpentine and water is about three inches above the bend. The upward pressure at this surface separating the two liquids, due to the head of water equal to the vertical

[1] If the water supply is at a very high pressure the U-tube will not be high enough to measure the pressure, and the experiment must be omitted.

distance between A and B, must be equal to the downward pressure due to the head of turpentine, BC. The vertical distance between A and B is equal to AD, where D is at the same level as B, so that the head of water at B is equal to the height AD. But the pressure is in each case proportional to the head of liquid and to the density of the liquid ; therefore—

FIG. 27. ($\frac{1}{12}$.)

CB × (density of turpentine) = AD × (density of water)

or—

$$\text{Density of turpentine} = \frac{AD}{CB}$$

since the density of water is 1.

Compare by this method the densities of turpentine, paraffin oil, and mercury, with that of water. Also compare the density of mercury with that of paraffin oil.[1] Enter your results as in the following example :—

Height of surface A of water above stand = 56·5 cm.
" " B " " = 7·7 "
∴ Head of water (AD) = 48·8 "
Height of surface C of turpentine above stand = 63·3 "
" " B " " " = 7·7 "
∴ Head of turpentine (CB) = 55·6 "

$$\text{Hence, } \frac{\text{Density of turpentine}}{\text{Density of water}} = \frac{AD}{CB} = \frac{48·8}{55·6} = 0·877$$

EXERCISE 34.—*Comparison of the densities of two liquids which mix by means of the U-tube.*

Apparatus :—U-tube ; metre scale ; mercury ; salt solution.

The method used in the last exercise cannot be employed if the liquids, the densities of which are to be compared, mix. Under these circumstances first introduce some mercury into the U-tube. This mercury will stand at the same level in the two tubes. Carefully stick a piece of gummed label round one of the limbs so that the edge of the label is exactly on a level with the surface of the mercury. Fill one limb of the tube to within about two inches of the top with the less dense of the two liquids to be compared, then

[1] The tube must be carefully cleaned between each set of measurements.

carefully pour the other liquid into the second limb till the mercury comes back to the same level in each limb, as shown by the surface of the mercury being opposite the edge of the paper mark. When introducing the first liquid do not add enough to drive the mercury right round the bend; if there is any chance of this happening pour some of the other liquid into the second limb, and then continue filling the first limb. If too much liquid has been added some may be removed with a pipette, or by means of a strip of blotting-paper. Measure the height of the top and bottom of each column of liquid from the stand, and thus obtain the heights of the liquid columns.

Since the mercury stands at the same height in the two limbs, we have, by the same reasoning as in the previous exercise,—

$$\frac{\text{Density of liquid in left limb}}{\text{Density of liquid in right limb}} = \frac{\text{height of liquid column in right limb}}{\text{height of liquid column in left limb}}$$

Compare by this method the density of a saturated solution of common salt with that of water. Enter your results as in Exercise 33.

EXERCISE 35.—*Comparison of the densities of two liquids which mix by Hare's apparatus.*

Apparatus:—Hare's apparatus; millimetre scale; supply of liquids such as saturated solution of common salt, milk, etc.

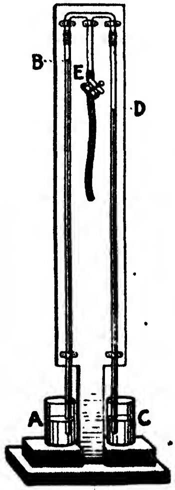


FIG. 28. (1/12)

Hare's apparatus (Fig. 28) consists of two long glass tubes connected at the top by a T-piece. A length of india-rubber tube is attached to the third branch of the T-piece, and can be closed when necessary by means of a pinchcock, E. The lower end of the tubes dip into two small beakers, containing the two liquids under experiment. By suction at the end of the rubber tube the liquids are drawn up into the tubes till the surface of the liquid in one tube nearly reaches the top. Measure the height of the top of each liquid column, and also the height of the surface of the liquid in each beaker above the stand, and hence get the height of the column of each liquid above the free surface of the liquid. As the tops of the columns are in connection, through the T-piece, the pressure at the top of each of the columns is the same.

The pressure at the free surfaces of the two liquids in the beakers is also the same. Therefore :—

$$\frac{\text{Density of liquid in tube AB}}{\text{Density of liquid in tube CD}} = \frac{\text{height of column CD}}{\text{height of column AB}}.$$

Compare by means of Hare's apparatus the densities of the following liquids—water, milk, and saturated solution of common salt. Enter your results as in the following example :—

Height of top of column of milk above stand = 57·5 cm.
Height of surface of milk in beaker above stand = 7·6 cm.

∴ Height of column of milk = 49·9 cm.
Height of top of column of water above stand = 59·8 cm.
Height of surface of water in beaker above stand = 8·4 cm.

∴ Height of column of water = 51·4 cm.

Hence—

$$\frac{\text{Density of milk}}{\text{Density of water}} = \frac{51\cdot4}{49\cdot9} = 1\cdot03.$$

∴ (since density of water = 1) density of milk = 1·03.

Principle of Archimedes.—When a body is partly or wholly immersed in a liquid, the liquid exerts an upward pressure on the body equal to the weight of the volume of liquid displaced by the body. Or, in other words, the loss of weight of a body when immersed in a liquid is equal to the weight of a volume of the liquid, equal to the volume of the body. The above is a statement of what is called the *Principle of Archimedes*, since Archimedes was the first to discover this important law in hydrostatics.

EXERCISE 36.—*Proof of the principle of Archimedes.*

Apparatus :—Balance ; solid and hollow cylinders ; beaker.

In order to prove the principle of Archimedes, you are supplied with a hollow cylinder, and a solid metal cylinder which exactly fills the inside of the hollow cylinder. Hang the two cylinders from the hook which carries the left-hand pan of the balance, the hollow cylinder being uppermost (Fig. 29), and counterpoise with shot and tinfoil. Then place a beaker of water so that the solid cylinder is completely immersed, supporting the beaker on a small stand in such a way that the movements of the pan of the balance are not

interfered with. The equilibrium of the balance will in this way be upset, the cylinder apparently losing weight. Carefully pour water into the hollow cylinder till equilibrium is again secured. It will be found that when this happens the hollow cylinder is exactly full. Since you have added to the left-hand pan a volume of water

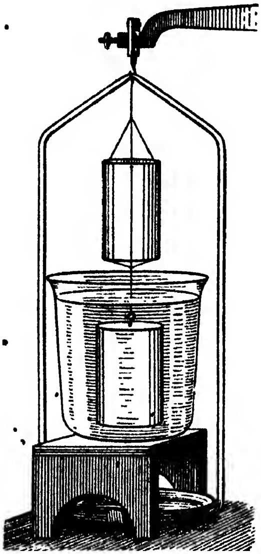


FIG. 29. (4.)

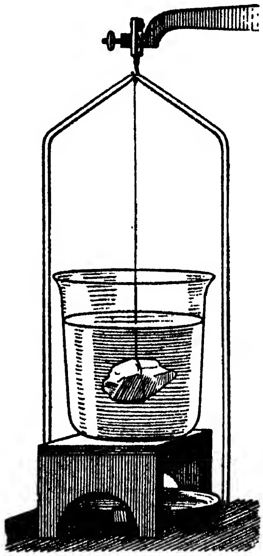


FIG. 30. (4.)

equal to that of the immersed solid, and the weight of this volume of water exactly compensates the loss of weight of the solid cylinder when immersed in water, this experiment is a proof of the truth of the principle of Archimedes.

Repeat the experiment, immersing the cylinder in a saturated solution of common salt, and filling the hollow cylinder with the same solution.

EXERCISE 37.—*Density of a solid more dense than water.*

Apparatus :—Balance ; beaker ; solids.

Since, when a solid is immersed in water, the loss of weight is equal to the weight of a volume of water equal to that of the solid ; if we weigh a solid first in air, and then when immersed in water, the difference in the two weights will be the weight of a volume of water equal to that of the solid. But we know the volume of any

given weight of water, and hence we can immediately calculate the volume of the body. Knowing the mass and volume, we can then find the density, since density $= \frac{\text{mass}}{\text{volume}}$.

In applying this method suspend the solid by a fine *silk* thread from the hook carrying the left-hand pan of the balance, and weigh. Then completely immerse the body in a beaker of water (Fig. 30) supported as in the last exercise, and again weigh. Care must be taken to remove all air bubbles which may be attached to the body when immersed in the water. This may be done by rubbing the body with a small camel's-hair brush.

Determine in this way the volume and density of the solids supplied, entering your results as in the following example :—

$$
\begin{aligned}
\text{Weight of solid in air} &= 13{\cdot}07 \text{ grms.} \\
\text{,,} \quad \text{,, in water} &= \underline{\ 7{\cdot}93\ } \text{ ,,} \\
\therefore \text{Weight of water displaced} &= 5{\cdot}14 \text{ ,,} \\
\therefore \text{Volume of body} &= 5{\cdot}14 \text{ c.c.} \\
\therefore \text{Density of body} &= \frac{\text{mass}}{\text{volume}} = \frac{13{\cdot}07}{5{\cdot}14} = 2{\cdot}54.
\end{aligned}
$$

EXERCISE 38.—*Density of a solid less dense than water.*

Apparatus as in previous exercise.

In the case of a body, such as a piece of wax or wood, which floats in water, we cannot directly weigh it when immersed in water, since it will not sink. Under these circumstances some heavy substance must be attached to the body to act as a "sinker." First weigh the sinker in air and then in water, suppose the loss of weight to be w grammes. Next attach the sinker to the substance, and weigh in air and in water, and let the loss of weight be W grammes. Since the substance under experiment is lighter than water, it will tend to buoy the sinker up, and therefore W will be greater than w. The difference between W and w will be the loss of weight of the substance when immersed in water, and hence the volume is $(W - w)$ c.c. The following example will assist in making the above explanation clear.

$$
\begin{aligned}
\text{Weight of sinker in air} &= 5{\cdot}21 \text{ grms.} \\
\text{,,} \quad \text{,, water} &= \underline{\ 4{\cdot}75\ } \text{ ,,} \\
\text{Loss of weight of sinker} &= 0{\cdot}46 \text{ ,,} \\
\therefore \text{Volume of sinker} &= 0{\cdot}46 \text{ c.c.}
\end{aligned}
$$

$$\begin{aligned} \text{Weight of substance + sinker in air} &= 12{\cdot}01 \text{ grms.} \\ \text{,,} \quad \text{,,} \quad \text{,,} \quad \text{water} &= \underline{4{\cdot}38} \quad \text{,,} \\ \text{Loss of weight of substance and sinker} &= 7{\cdot}63 \quad \text{,,} \\ \therefore \text{ Volume of substance + sinker} &= 7{\cdot}63 \text{ c.c.} \\ \therefore \text{ Volume of substance} &= 7{\cdot}63 - 0{\cdot}46 = 7{\cdot}17 \text{ c.c.} \end{aligned}$$

$$\begin{aligned} \text{Mass of substance} &= (\text{mass of substance + sinker}) \\ &\quad - (\text{mass of sinker}) \\ &= 12{\cdot}01 - 5{\cdot}21 = 6{\cdot}80 \text{ grams.} \end{aligned}$$

$$\therefore \text{ Density of substance} = \frac{\text{mass}}{\text{volume}} = \frac{6{\cdot}80}{7{\cdot}17} = 0{\cdot}952.$$

Determine by the above method the density of paraffin wax, and of a piece of varnished pine, entering your results as in the above example. A small piece of sheet lead may be used as a sinker.

EXERCISE 39.—*Density of a liquid by weighing a solid first in water, then in the liquid.*

Apparatus:—Balance; beaker; solid; various liquids, such as milk, vinegar, paraffin oil, etc.

By weighing a body first in air and then in water, we can calculate, as in the previous exercises, its volume. If now the body is weighed when immersed in some other liquid, the loss of weight will be the weight of a volume of this liquid equal to the volume of the body. But the volume of the body is known from the loss of weight when weighed in water; hence we know the mass and the volume of a certain quantity of the given liquid, and can calculate the density.

Determine by this method the density of milk, vinegar, paraffin oil, etc., using one of the solids employed in Exercise 37. Enter your results as in the following example:—

$$\begin{aligned} \text{Weight of solid in air} &= 13{\cdot}07 \text{ grms.} \\ \text{,,} \quad \text{,,} \quad \text{water} &= \underline{7{\cdot}93} \quad \text{,,} \\ \text{Hence loss of weight of solid} &= 5{\cdot}14 \quad \text{,,} \\ \therefore \text{ Volume of solid} &= 5{\cdot}14 \text{ c.c.} \\ \text{Weight of solid in milk} &= 7{\cdot}79 \text{ grms.} \\ \text{Hence loss of weight of solid in milk} &= 5{\cdot}28 \quad \text{,,} \\ \therefore \text{ Weight of volume of liquid displaced} &= 5{\cdot}28 \text{ grms.} \\ \text{But volume of liquid displaced} = \text{volume of solid} &= 5{\cdot}14 \text{ c.c.} \end{aligned}$$

$$\therefore \text{ Density of milk} = \frac{\text{mass}}{\text{volume}} = \frac{5{\cdot}28}{5{\cdot}14} = 1{\cdot}027.$$

Flotation.—When a solid is less dense than the liquid in which it is immersed, the loss of weight, or upthrust of the liquid, will be greater than the weight of the body. For the upthrust due to the liquid is, by the principle of Archimedes, equal to the weight of a volume of the liquid equal to the volume of the solid. If the solid is less dense than the liquid, a given volume of the solid will weigh *less* than an equal volume of the fluid, and hence the upthrust is greater than the downward pull exerted by the earth on the solid, *i.e.* the weight. If, therefore, the solid is not held down, it will rise to the surface of the liquid. When it reaches the surface, part will project out of the liquid, this part no longer displaces any of the liquid, so that the volume of fluid displaced is reduced, and therefore the upthrust due to the liquid is also reduced. The downward pull due to the earth, however, remains unaltered; and the body will go on rising till the upthrust due to the displaced liquid is exactly equal to the down-pull due to the earth, *i.e.* the weight. Thus, when a body floats on a liquid the weight of the liquid displaced must be equal to the weight of the body.

EXERCISE 40.—*Flotation.*

Apparatus :—Blocks of varnished wood of various shapes ; glass dish containing water ; metre scale and rough balance.

Float a rectangular block of wood on water, and note the depth to which it is immersed. Since the block may not be immersed to quite the same extent all round, measure the depth at each corner, and take the mean. In order to facilitate this measurement, a series of division marks have been made along the four shorter edges of the block. By placing the eye a little below the level of the surface of the water, the position of the surface (with reference to these division lines) can be noted, and then the block removed and the distance from the bottom surface of the block to these points measured. Calculate the volume of the part immersed, and hence the weight of the water displaced. Also weigh the block, and show that the weight of water displaced is equal to the weight of the block.

Repeat the experiment, using blocks of various shapes. Enter

your results as in the following example, in each case making a lettered sketch of the block in the position in which it floated :—

Depth below the surface of corner A = 2·54 cm.
,, ,, ,, ,, B = 2·50 cm.
,, ,, ,, ,, C = 2·55 cm.
,, ,, ,, ,, D = 2·57 cm.
Mean depth of immersion = 2·54 cm.
Area of under surface of block = length × breadth
= 10·15 × 6·32 = 64·15 sq. cm.
∴ volume immersed = area × depth
= 64·15 × 2·54 = 162·9 c.c.
Volume of water displaced = 162·9 c.c.
Weight of water displaced = 162·9 grms.
Weight of block (obtained by weighing) = 162 grms.

EXERCISE 41.—*Measurement of the density of liquids by flotation.*

Apparatus:—Glass tube 12 in. long and ½ in. in diameter, closed at both ends, and weighted with mercury; tall glass cylinder; scale.

You are supplied with a piece of glass tube, closed at both ends, and weighted with a little mercury so that it will float upright. Float this tube in a tall glass cylinder filled with water, and measure the length immersed. Measure the diameter of the tube with the slide calipers, and calculate the area of cross section, see p. 28. Hence calculate the volume of the part *immersed* by multiplying the cross section by the length immersed. The weight of this volume of water is equal to the weight of the instrument: prove this by actual weighing. Next float the tube in a saturated solution of common salt, and again calculate the volume immersed. The weight of this volume of salt solution is equal to the weight of the instrument. Hence calculate the density of the salt solution.

If we denote the area of the cross section of the tube by A, and if x is the length of the tube immersed in water, and y the length immersed in the salt solution: then Ax is the volume of water displaced, and Ay is the volume of salt solution displaced. Therefore the weight of water displaced is Ax × (density of water), and the weight of salt solution displaced is Ay × (density of solution). But

the weight of liquid displaced is in each case equal to the weight of the tube. Therefore—

$$Ax \times (\text{density of water}) = Ay \times (\text{density of solution}),$$

$$\text{or} \frac{\text{Density of solution}}{\text{Density of water}} = \frac{Ax}{Ay} = \frac{x}{y}$$

That is, the densities of the liquids are *inversely* as the lengths of tube immersed.

Measure the depth to which the tube sinks in salt solution, milk, paraffin oil, and methylated spirit, and calculate the densities of these liquids.

The Hydrometer.—Instead of measuring the depth to which the tube in the last exercise sank in the different liquids by means of a separate scale, we might have had a paper scale fixed inside the tube, so that the length immersed could be read off through the glass. Again, instead of having the scale inside the stem of the instrument graduated to show the length immersed, and then from this length calculating the density of the liquid, it might be graduated to give the density direct. Thus, using the same notation as in the preceding exercise, at a distance, x, from the end, such a scale would read 1·00, since, when the instrument is placed in water (density 1), it sinks to this point. At a distance, y, from the end, in the same way, the scale would read 1·22, this number expressing the density of the salt solution in which the instrument sank to this point. Continuing in this way, a scale would be constructed so that the density of the liquid in which the instrument is floated could be directly read off.

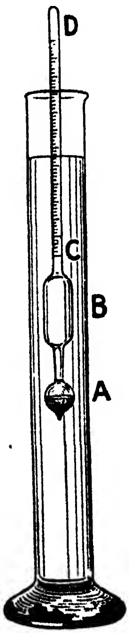


Fig. 31. (¼.)

An instrument on this principle, and called a hydrometer, is shown in Fig. 31. The small bulb A is filled with mercury, in order that the instrument may float upright. To reduce the length of the instrument the lower part is blown into a bulb, B; the upper

raise the U-tube itself till the flow stops. When this occurs, note the relative level of the end of the shorter limb and of the surface of the water in the beaker into which the other limb dips. If the level of the end of the outside limb is above that of the surface of the water in the beaker, will the water flow out?

A U-tube used in this manner is called a *siphon.*

From the results of the above experiments, give the conditions as to the levels of the liquid in two vessels connected by a siphon in order that the liquid may flow from one vessel into the other. Also give the conditions which have to be fulfilled that we may be able to draw off liquid from a vessel with a siphon.

Explain the flow of liquid through a siphon, by considering the head of liquid at each end of the siphon; illustrate your answer by means of a diagram.

ADDITIONAL EXERCISES IN HYDROSTATICS.

1. Take 20 grms. of common salt and add enough water to make up the solution to 100 c.c. Determine the density. To 50 c.c. of this solution add 50 c.c. of water, and determine the density. This solution will contain 10 grms. of salt in 100 c.c. Repeat the process so as to determine the densities of solutions containing 5 and 2·5 grms. of salt in 100 c.c. respectively. Enter your results in a table, the first column containing the quantity of salt in 100 c.c. of the solution, and the second column the corresponding density. The density of sea water is 1·03; from your results find approximately how much salt is contained in 100 c.c.

2. Determine the density of a very small piece of ebony or amber by making a solution of salt so that the solid just floats, and then measuring the density of the solution with Hare's apparatus.

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PART III.—THE BAROMETER AND BOYLE'S LAW.

SECTION I.—THE BAROMETER.

TAKE a glass tube, about 36 inches long, and closed at one end, and fill it with water. Close the end with your finger, and invert the tube, dipping the end below the surface of some water in a beaker. Remove your finger, and note that the water still completely fills the tube.

At the open end of the tube there is a downward pressure equal to the weight of the column of water AB (Fig. 32), while apparently the upward pressure is only equal to the weight of a column of liquid of height, CB. Hence, if this were the only upward pressure acting, the water would run out of the tube till the level of the surface inside and outside the tube was the same. From the fact that the water does not run out in this way, we are led to conclude that the upward pressure at B must be greater than that due to the "head" CB. This increased pressure is due to the fact that the atmosphere is also a fluid having weight, and hence exerts a pressure on the surface of the water, which pressure is transmitted by the water. Suppose that the pressure exerted by the atmosphere is equal to that which would be exerted by a column of water 10 metres high.

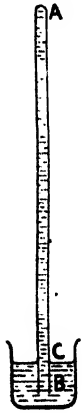

FIG. 32.

Then, if a tube were taken 11 metres long, the downward pressure at B would be equal to the weight of a column of water 11 metres high, the upward pressure being equal to the

weight of a column of water having a height of 10 metres + the height CB. Hence, if CB is less than one metre, the downward pressure at B would be greater than the upward pressure, and therefore the water would run out of the tube till the height of the water column in the tube was 10 metres + CB. Since it would be very inconvenient to use a tube 10 metres long, it is usual to use a liquid of a much greater density than water, so that an equal downward pressure at B may be obtained with a shorter column of liquid. The liquid best suited for this purpose is mercury, the density of which is 13·6 times that of water, so that a tube $\frac{1}{13.6}$ of the length required in the case of water can be employed.

EXERCISE 44.—*Barometric height.*

Apparatus:—Glass tube, 36 inches long, closed at one end; mercury;[1] metre scale.

Fill a *clean and dry* glass tube, about 36 inches long, and closed at one end, with mercury up to within half an inch of the end. Close the end with the finger, and, by gradually inverting the tube, run the bubble of air left *slowly* up and down the tube, so as to remove any small bubbles of air sticking to the sides of the tube. Then completely fill the tube with mercury, and, again closing the end with your finger, invert the tube, and dip the end beneath the surface of some mercury contained in a small wooden trough.[2] Fix the tube upright in a retort clamp.

It will be found that the mercury does not completely fill the tube, but that the top part of the tube is empty. Measure the height of the column of mercury above the surface of the mercury

[1] Unless special precautions are taken, it will be found that there is a very great waste of mercury in the laboratory. It is best, if possible, to have a table reserved for all experiments in which mercury is used. This table ought only to be about two feet high; and there should be a beading, about an inch high, all round the edge. A small hole at one corner, which can be closed by a cork, serves to draw off any mercury spilt. It is a good thing to cover the floor under this table and for about a yard on each side with oilcloth; and to nail strips of wood, about one thirty-second of an inch thick, all round the edge. If it is not possible to have a special table reserved for experiments involving the use of mercury, all such experiments ought to be performed over shallow wooden trays, about 24 × 18 inches and 2 inches deep.

[2] Small wooden boxes with one side made of glass, and the edges cemented with marine glue, are very useful for experiments with barometer tubes.

in the trough. This height is called the BAROMETRIC HEIGHT. Empty the tube and refill, again measuring the barometric height: the value obtained ought to be the same as before; if not, some air bubbles have probably been left sticking to the side of the tube in one or other of the experiments, and they should be repeated.

EXERCISE 45.—*Barometer (continued).*

Apparatus:—As in Exercise 44.

In the previous exercises the barometer tube was placed vertical; now incline the tube from the vertical, and fix in this new position by means of the retort clamp. Measure the *vertical* distance between the level of the mercury inside and outside the tube. The best way of making this measurement is to measure the vertical height of the end of the mercury column above the surface of the table, and then measure the height of the surface of the mercury in the trough above the table. The difference gives the height required. Repeat the experiment, inclining the tube more and more each time till the mercury entirely fills the tube. Enter your results in a table, as below.

Position of Tube.	Height above Table of the Surface of the Mercury in		Barometric Height.	Distance of Top of Mercury Column from closed End of Tube.
	Trough.	Tube.		
Vertical.				
Inclined.				
,,				
,,				
,,				

From the values obtained, it will be evident that the vertical distance between the levels of the surfaces of the mercury, *i.e.* the barometric height, remains the same, whether the tube is vertical or inclined, so long as the mercury does not completely fill the tube.

EXERCISE 46.—*Barometer (continued).*

Apparatus:—The arrangement shown in Fig. 33; metre scale.

In order to show that the barometric height does really depend on the pressure of the air on the free surface of the mercury in the trough, you are supplied with a mercury barometer, the lower end of of which dips in some mercury contained, not in an open trough,

but in a bottle, A (Fig. 33), which is closed air-tight by an indiarubber cork. Two other tubes, besides the barometer tube, pass through this cork. Of these tubes one, B, is bent, and forms a manometer (see p. 40), the lower part of the bend being filled with mercury. The other tube, C, has a short length of indiarubber tubing attached, which tube can be closed with a pinchcock, D. By sucking or blowing down this tube, the pressure of the air inside the bottle A can be made either less or greater than the pressure of the external air, while the difference between the inside and outside pressure can be read off on the manometer B.

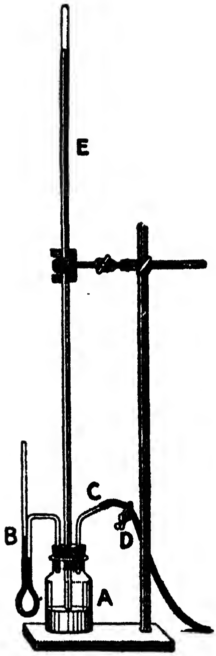

FIG. 33. ($\frac{1}{10}$.)

Open the pinchcock D so that the air inside the bottle is in free communication with the external air, and measure the height of the mercury column. This is the barometric height. Then blow down C and close the pinchcock D, so that the pressure on the air inside the bottle is increased. Again measure the height of the mercury column in E, and also the difference in the level of the mercury in the two branches of the manometer B. This difference gives the amount by which the pressure of the air inside the bottle exceeds the pressure of the external air. According to what has been said on p. 53, the height of the column E gives the pressure to which the air inside the bottle is subjected. Hence the barometric height added to the difference in level in B ought to be equal to the height of E. See if your observations bear out this conclusion.

Repeat the experiment by sucking air out of the bottle, and enter your results in a table, as in the following example:—

Condition of Air in A.	Height of Column in E.	Difference of Level in B.	Barometric Height + or − Difference of Level in B.
Open to air ..	76·4 cm.	0·0 cm.	76·4 cm.
Compressed ..	79·8 ,,	3·3 ,,	79·7 ,,
Rarefied ..	72·5 ,,	3·9 ,,	72·5 ,,

If your readings have been taken with care, and the cork in the bottle does not leak,[1] the numbers in the second and fourth columns will be equal; showing that, by altering the pressure of the air on the surface of the mercury in the bottle A, the height of the column of mercury E alters, and the amount by which it alters is equal to the amount by which the pressure of the air in A is altered.

EXERCISE 47.—*Effects of the introduction of air, water, etc., on the height of the barometric column.*

Apparatus:—As in Exercise 44, with the addition of a small pipette with bent delivery tube, and a supply of ether, etc.

Fill a barometer tube, and measure the height of the barometric column. Then introduce a very small quantity of air into the tube. This may be accomplished by means of a piece of glass tube, the end of which has been drawn out and bent round (see Fig. 34). Dip the bent end below the surface of the mercury in the trough, and introduce the point A into the end of the tube; then gently blow at B, so as to force a small bubble of air into the tube. Now measure the height of the mercury column. Introduce several bubbles in succession, measuring the height of the column after the introduction of each bubble. Describe carefully in your note-book what you have done, and what occurs when air is introduced, entering the measurements of height as follows:—

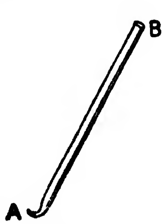

FIG. 34. (⅙.)

Height of mercury column before the introduction of air = ... cm.
„ after the introduction of 1st bubble of air = ... cm.
„ „ „ „ 2nd „ „ = ... cm.
etc.

Again fill the tube with mercury, and invert over the trough, measuring the barometric height. Then, by means of the pipette, carefully introduce a little water into the tube, and measure the height of the mercury column. Introduce more water, and again measure the height of the column. As before, write a description of the experiment, in particular noting any difference between the effect on the height of the column of the introduction of successive small quantities of air and water.

Repeat, using ether in place of water. In what respects do the

[1] After compressing the air in A watch the manometer B, and see if the pressure alters; if the mercury gradually falls it means the cork is leaking. This may be remedied by running melted paraffin wax round the places where the cork and glass meet.

effects produced by ether and by water resemble one another, and in what respects do they differ?

The experiments in the previous exercise have shown that, when air is introduced into the space at the top of a barometer tube, the column of mercury is forced down. Since the introduction of the air into the tube has not altered the amount of the atmospheric pressure, the upward pressure at the open end of the tube remains the same. The downward pressure due to the column of mercury, however, is reduced, since the height of the column, and therefore the "head," is reduced. Hence it follows that the air enclosed in the tube must be pressing on the upper surface of the mercury column, and this pressure serves to partly counterbalance the atmospheric pressure. When water is introduced in the same way, the column is reduced in height to a very much greater extent than would be due to the mere weight of the small quantity of water which has been introduced, and which floats on the surface of the mercury. The greater part of the depression is due to the fact that the water gives off steam or vapour which exerts a downward pressure. This question will be further considered when we are dealing with the subject of heat.

SECTION II.—BOYLE'S LAW.

EXERCISE 48.—*Boyle's Law.*

Apparatus :—Boyle's law tube on stand ; mercury ; metre scale.

You are supplied with a U-shaped tube fixed to a vertical stand. The end A (Fig. 35) of the shorter leg of the tube is closed, while the other end, B, is open. It is important that the end A should be sealed in such a manner that the end of the bore is not dome-shaped, but flattened, as shown on an enlarged scale at E. Pour a little *clean and dry* mercury into the tube, and by inclining and shaking the tube arrange that the mercury stands at about the same height in each limb. Measure the height of the surface of the mercury in each limb, and of the end of the *bore* of the shorter limb above the surface of the stand. The difference between the heights of the mercury in the two limbs, together with the height of the barometric column, gives the total pressure to which the air enclosed in the shorter limb is subjected. Read the barometer, and enter the height

in your note-book. Then pour some more mercury into the open limb, so that the mercury stands about 6 inches higher in one limb than in the other. Again measure the heights of the mercury in the two limbs above the stand. Continue in this manner, increasing the pressure by about 6 inches of mercury each time, till the open tube is full to the top.

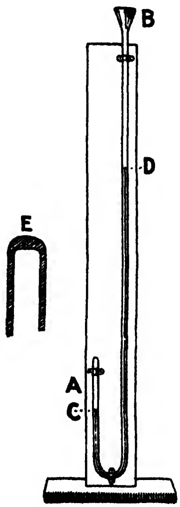

FIG. 35. ($\frac{1}{10}$.)

Since the bore of the tube is cylindrical, and the volume of a cylinder is equal to the product of the area of cross section into the length, it follows that the volume of the air enclosed in the short limb is proportional to the length of tube which it occupies. For if at one time the air occupies a length x of the tube, and at another time a length $2x$, and if the area of cross section of the tube is A, then the volumes in the two cases will be xA and $2x$A. That is, if the length occupied is doubled, the volume is also doubled. Hence we may take the *lengths* of the tube occupied by the air as representing the *volumes* under the various pressures.

The length of the air column can be obtained by subtracting the height of the surface of the mercury in the closed limb from the height of the top of the inside of the closed limb, both measured from the stand of the instrument. The total pressure acting on the air will be the difference in level of the mercury in the two limbs added to the barometric height. Enter your results in a table, as in the following example; and calculate and enter the corresponding pressures and volumes, and the product of the pressure into the volume.

Height of Mercury above the Stand in		Difference between Level of Mercury in two Limbs.	Barometric Height.	Total Pressure, in cm., of Mercury (= P).	Length of Air Column (= V).	P × V.
Closed Limb.	Open Limb.					
6·50 cm.	8·8 cm.	2·30 cm.	76·2 cm.	78·50	19·60 cm	1539
9·40 ,,	25·3 ,,	15·90 ,,	,,	92·10	16·70 ,,	1537
11·35 ,,	39·1 ,,	27·75 ,,	,,	103·95	14·75 ,,	1534
13·00 ,,	54·2 ,,	41·20 ,,	,,	117·40	13·10 ,,	1538
14·75 ,,	73·8 ,,	59·05 ,,	,,	135·25	11·35 ,,	1534
16·10 ,,	93·3 ,,	77·20 ,,	,,	153·40	10·00 ,,	1534

Boyle's Law.—From the last column of the table in the preceding exercise it will be evident that the product obtained by multiplying together corresponding values of the pressure and volume of the air is constant for such pressures as have been employed in the experiment. Hence it follows that the volume of a given quantity of air varies inversely as the pressure to which it is subjected, for if we double the pressure it is evident that if the product $P \times V$ is to remain constant the volume must be halved. This connection between the volume and pressure of air is called BOYLE'S LAW, since it was discovered by Robert Boyle in 1662.

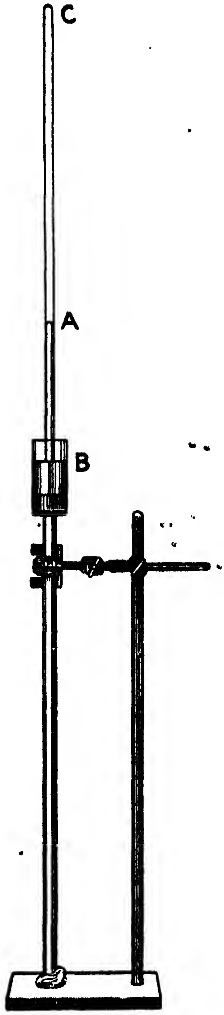

FIG. 36. ($\frac{1}{10}$.)

EXERCISE 49.—*To test Boyle's Law for pressures less than an atmosphere.*

Apparatus:—Straight glass tube, closed at one end, and about 36 inches long; tall glass cylinder; mercury; metre scale.

In the previous exercise the pressure to which the air was subjected was never less than the atmospheric pressure, or, as it is called, a pressure of one atmosphere. In order to test Boyle's Law for pressures less than an atmosphere, you are supplied with a straight glass tube, closed at one end. Fill this tube about *two-thirds* full of mercury, and, closing the end with the finger, invert the tube and place the open end below the surface of some mercury contained in a tall glass cylinder (Fig. 36). Fix the tube[1] so that the open end is only just below the surface of the mercury, and measure the height AB of the mercury column in the tube and the length AC of

[1] The cylinder may be placed on the floor, and the barometer tube held in a retort-stand placed on the table alongside.

the tube occupied by the air. Then lower the tube so that the open end is about six inches below the surface of the mercury, and again measure the height of the mercury column, and the volume of the air. Continue in the same way till the mercury stands at the same level inside and outside the tube. When this is the case, the air inside is at the atmospheric pressure, while in the other positions the pressure is equal to the barometric height less the height of the mercury column.

Calculate the values of the product P × V, and enter your results as in the following example :—

Height of Mercury Column.	Barometric Height.	Total Pressure = P.	Volume = V.	P × V
34·4 cm.	76·2 cm.	41·8 cm.	52·9 cm.	2210
27·0 ,,	,, ,,	49·2 ,,	45·0 ,,	2210
14·9 ,,	,, ,,	61·3 ,,	35 8 ,,	2200
0·0 ,,	,, ,,	76·2 ,,	28·8 ,,	2200

SECTION III.—GEOMETRIC REPRESENTATION OF VARYING QUANTITIES.

Suppose it is required to make a record of the exact position of some point, say a small ink-spot, on the surface of your table, so that if a sheet of paper were glued over the top of the table you could from such record place a dot on the paper exactly over the spot: one method which could be employed would be to measure the distance of the spot from the front edge of the table, and also the distance from the left-hand edge. By the distance between a point and a line (the edge of the table is a line), we mean the shortest distance between the point and the line, *i.e.* the distance measured along a line drawn through the point perpendicular to the line.

Prove by actual measurement that the *shortest* distance between a point and a line is along the perpendicular from the point to the line.

The distances of the point from the two edges of the table completely fix the position of the point. For suppose we are

told that a given point is 14 inches from the front edge, and 8 inches from the left-hand edge: then, if a line is drawn parallel to the front edge of the table, and at a distance of 14 inches from it, *all* the points which are 14 inches from the front edge of the table lie on this line. In the same way *all* the points which lie at a distance of 8 inches from the left-hand edge of the table lie on a straight line drawn parallel to this edge at a distance of 8 inches from it. Hence the given point must lie in *both* of these straight lines, and the only point which lies in *both* the lines is the point where they cross. These two distances tell us, therefore, exactly where the point lies.

Place a small dot on the surface of your table at the following points:—

1. 30 cm. from the front edge, and 15 cm. from the left-hand edge.

2. 21 cm. from the front edge, and 41 cm. from the left-hand edge.

The above method of fixing the position of a point in a plane, *i.e.* on a flat surface, by giving its distance from two fixed lines, is of great use. The two fixed lines, which practically are always taken at right angles to one another, are called the *axes of co-ordinates*, or, shortly, *the axes*. In the above examples the axes taken are the front and left-hand edges of the table. The distances of the point from the axes are called the *co-ordinates* of the point. The point O (Fig. 37), where the axes OX, OY meet, is called the *origin*. If P is any point, the co-ordinates of P are MP and NP. Since PNOM is a rectangle, NP is equal to OM, and MP is equal to ON. Hence, MP and OM may be taken as the co-ordinates of the point P.

It is usual to call the co-ordinate OM the *abscissa*, and the co-ordinate MP, or ON, the *ordinate* of P. If we are told that the abscissa of a given point is 4·3 cm., and the ordinate 2·7 cm., it means that, starting from the origin O, we must measure along OX a distance, OM, equal to 4·3 cm., then draw MP perpendicular to OX, and measure off a distance, MP, along this line equal to 2·7 cm. In order to save the

time which would be spent in measuring off the distances OM and MP, and in drawing the perpendicular MP, it is usual when a number of points with given co-ordinates have to be set out—an operation called plotting the points—to employ curve paper. Two of the darker lines are chosen as the axes,

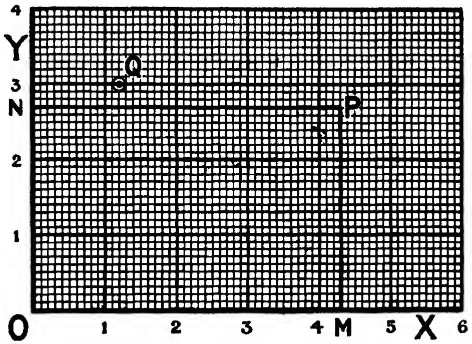

FIG. 37.

and then the distances OM, MP can be directly set off. Thus, in Fig. 37, starting from O, we go along OX, a distance of 4·3 cm., *i.e.* past four of the dark lines on to the third light line beyond, and then up this line past two dark lines, and stop on the seventh light line beyond.

EXERCISE 50.—*Plotting points on curve paper.*

Apparatus :—Curve paper ruled in millimetre squares.

On the piece of curve paper supplied to you, choose the dark line nearest the bottom of the sheet for the axis of X, and the one nearest the left-hand edge for the axis of Y. Number the whole centimetres, *i.e.* the dark lines, along the two axes, taking the point where the two axes cross as zero in each case (see Fig. 37). Then plot the following points, making a small dot with a sharp pencil at the required point, and surrounding this dot with a small circle as at Q (Fig. 37), where the first point has been plotted.

	Abscissa.	Ordinate.		Abscissa.	Ordinate.
(1)	1·2 cm.	3·0 cm.	(6)	6·7 „	3·8 „
(2)	1·8 „	4·7 „	(7)	6·3 „	1·4 „
(3)	3·0 „	5·6 „	(8)	4·0 „	0·2 „
(4)	4·0 „	5·8 „	(9)	2·6 „	0·6 „
(5)	5·4 „	5·4 „			

Loci.—In Fig. 38 a number of points have been plotted, these points, however, have not been simply placed at random, but all satisfy a certain condition—that is, they *all* lie on the same straight line. Further, it will be found that in every case the ordinate of each of the points is equal to twice the abscissa. Thus the abscissa of the point P is 2·0 cm., while the ordinate is 4·0 cm.

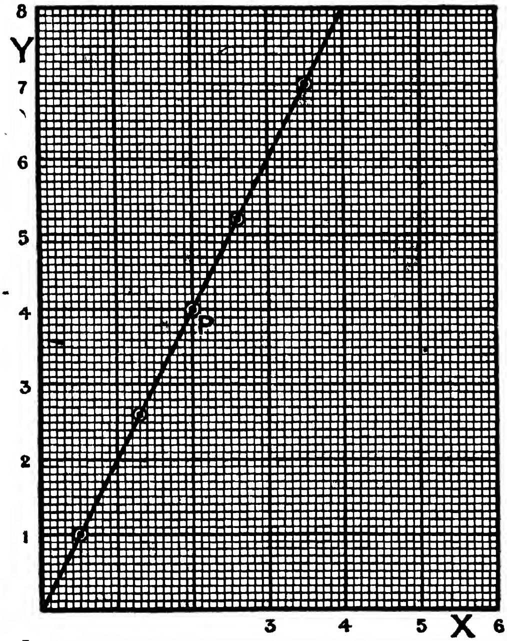

Fig. 38.

Suppose, now, we take any other point such that the ordinate is double the abscissa, say the point of which the abscissa is 2·9 cm. and the ordinate 5·8 cm., it will be found that this point lies on the *same* straight line as before. Hence we see that all points for which the ordinates are double the abscissæ lie on a certain straight line. This line is therefore called the *locus* of all points for which the ordinates are double the abscissæ.

EXERCISE 51.—*Loci.*

Apparatus:—Curve paper.

What is the locus of all points such that the ordinates are half the abscissæ? To solve this question, take a number of values for the abscissa, say 0·6, 1·0, 2·0, 2·4, 3·7, etc., and calculate the corresponding ordinates; these will be 0·3, 0·5, 1·0, 1·2, 1·85, etc. Next plot these points on a piece of curve paper, and see if you can detect any connection between them.

What is the locus of all points for which the sum of the abscissa and ordinate is equal to 10? (For example, the points of which the abscissæ are 3 and 8, and therefore the ordinates $10 - 3$, and $10 - 8$ (*i.e.* 7 and 2), satisfy this condition.)

What is the locus of the points plotted in the previous exercise?

Algebraical Representation of Loci.—In the above examples we see that all points of which the co-ordinates fulfil certain conditions lie on a certain line (not necessarily straight) called the locus. Since this is true for all points which satisfy the given condition, we may conveniently use algebraic notation in which symbols are used instead of concrete numbers. Thus, if we agree to let x represent the abscissa of any point, and y represent the *corresponding* ordinate, then the first locus considered—namely, that of all points such that the ordinate is double the abscissa—may be represented by the equation—

$$y = 2x;$$

since for any value of x, if the point is to lie on the locus, the corresponding value of y must be twice as great.

EXERCISE 52.—*Loci (continued).*

Using x to represent the abscissa of *any* point on the locus, and y the *corresponding* ordinate, write down algebraically the first two loci plotted in Exercise 51.

Plot the following loci $x = y$; $x - y = 2$.

Graphical Representation of Boyle's Law.—In Exercise 48 you obtained a number of corresponding values for the pressure and volume of a given mass of air. For each value of the pressure there was one and only one

corresponding value of the volume. Suppose we now agree to let distances measured along the axis of X represent the volume of the air, and distances measured along the axis of Y represent the pressure to which the air is subjected. A suitable scale to employ is one on which 1 cm. along the axis

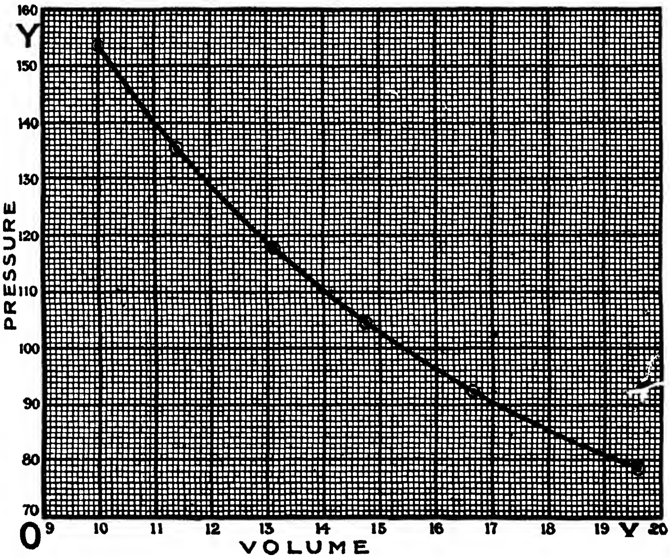

FIG. 39.

of Y represents an increase of pressure of 10 cm. of mercury, and 1 cm. along the axis of X represents an increase of volume of ·1 cm. along the cylindrical tube. Since, however, the pressure employed in Exercise 48 was never less than 70 cm. of mercury, it is unnecessary to start the ordinates at 0, but it will be sufficient if, as in Fig. 39, where the results given in the example on p. 59 are plotted, we start at 70. In the same way we may start the abscissæ at 9. Thus the point O corresponds to a pressure of 70 cm. of mercury, and a volume of 9 cm. of the tube. On plotting the points in this manner, we find that a smooth curve can, as shown in the figure, be drawn through the points. This curve represents the

connection between the volume and pressure of the particular mass of air which was enclosed in the tube during the experiment, and from such a curve we can find the volume this mass of gas will occupy under any pressure between the extreme pressures employed in the experiment—that is, between 78 and 154 cm. of mercury; or, conversely, given the volume, we can find the corresponding pressure.

EXERCISE 53.—*To plot the results of experiments made to verify Boyle's Law.*

Apparatus:—Curve paper.

On a sheet of curve paper plot the results of the experiments made in Exercises 48 and 49, making the abscissæ represent the volumes and the ordinates the pressures, and employing the same scale as that used in Fig. 39. You will have two separate sets of points since the mass of air on which the experiment was made was different in the two exercises. Through the points of each set draw a curve in pencil, and, when you have succeeded in drawing an even and smooth curve, ink it in. Be careful to enter the scales of pressure and volume along the two axes as is done in the figure. Read off the corresponding pressures and volumes for a point between each of the observed points, and prove by actual multiplication that the product P × V is also constant for these points, and equal to the product obtained for the observed values of the pressure and volume.

If your results have not been carefully taken you may find it impossible to draw a smooth curve *through* all the points. If any particular point lies a long way off the line which would pass through the others, see if you have not made some mistake, either in calculating the total pressure or in plotting the point. If no such mistake has been made, you must draw the curve so as to pass as near all the points as possible, and so that there may be as many points above the curve as below.

ADDITIONAL EXERCISES IN PLOTTING CURVES.

1. Draw the straight line for which $x = 2{\cdot}54\,y$. Here, when $x = 0$, $y = 0$, so that the line goes through the origin. Since 1 inch = 2·54 cm., this curve may be used to convert a length

from centimetres to inches, or from inches to centimetres. Find, from the curve the number of centimetres in 1 foot (12 in.), and in 4 inches. Also the number of inches in 15·2 cm. and 7·8 cm.

2. Draw the locus $x^2 = y$. To do this give x the values 0, 1, 2, 3, 4, etc., and calculate the corresponding values of y. Plot these points on curve paper, and through them draw a smooth curve. Show how this curve may be used to find squares and square-roots, illustrating your answer by examples.

3. Plot a curve showing the results of the measurements of density of salt solutions made in the exercise on p. 52, and from your curve read off the quantity of salt in 100 c.c. of sea water.

PART IV.—MECHANICS.

EXERCISE 54.—*Calibration of a spring balance.*

Apparatus:—Spring balance; weights: curve paper.

Unhook the pill-box lid, D, Fig. 40, which forms the scale-pan of the spring balance, and, placing it in the left-hand pan of an ordinary balance, add shot or tinfoil till it weighs exactly 10 grammes. Fix the spring balance upright in the clamp of a retort-stand, so that when the scale-pan is attached the string BC lies parallel to the edge of the graduated scale. Take the reading on the scale opposite the small knot A, which serves as an index. This reading gives the position of the index when the spring is stretched by a force equal to the weight of 10 grms., since the scale-pan and shot weigh 10 grms. Increase the stretching weight 10 grms. at a time, till the total load is 100 grms., taking in each case the reading opposite the index A.

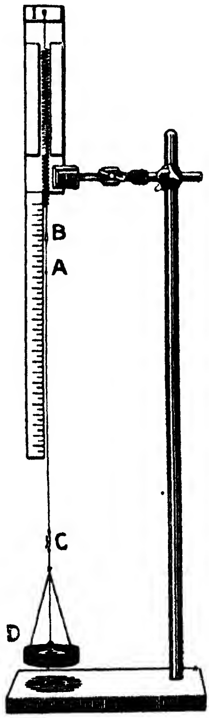

FIG. 40. ($\frac{1}{11}$.)

Enter your results in a table, giving the reading for the index A in one column and the corresponding load in a second column, remembering to add 10 grms. to the weights in the pan for the scale-pan and shot. Also plot the results on a sheet of curve paper, taking the loads as abscissæ, and the readings on the graduated scale as ordinates. A suitable scale to adopt is one in which one centimetre along the axis of X represents 10 grms., and one centimetre along the axis of Y represents 2 cm. on the graduated scale. Draw a curve (in this case it is a straight line) through all the observed points, and write the

number of the balance alongside this line. By means of this curve, which is called a *calibration curve*, the stretching force acting on the spring for *any* reading on the graduated scale can immediately be read off.[1]

EXERCISE 55.—*Use of spring balance with calibration curve to measure mass.*

Apparatus:—Spring balance calibrated in previous exercise.

Measure the mass of the pieces of metal used in Exercise 18, by placing them in the scale-pan of the spring balance, and taking the reading on the divided scale. From this reading, by means of the calibration curve, obtain the stretching force in grammes. This stretching force is the force with which the earth attracts the given body, together with the scale-pan and the shot it contains (*i.e.* 10 grms.). Hence, by deducting 10 grms. from the reading given by the curve, the mass of the body is obtained. Enter your results in a table, as below:—

Reading on Scale of Balance No.	Corresponding Value of Stretching Force obtained from Curve.	Mass of Body.
.... cm.	.... grms.	.. .. grms.

EXERCISE 56.—*The lever.*

Apparatus:—Box-wood metre scale;[2] support; balance and weights; shot; small scale-pan.

You are supplied with a box-wood metre scale having a small hole bored through near the edge at the 50-cm. division. Pass a stout sewing-needle through this hole, and support the needle on two wooden blocks in the manner shown at A, Fig. 41. If the scale does not swing horizontally, weight the lighter side with tin-foil till it does. At one end place a block of wood, B, in which a

[1] As the spring balances will be used in several experiments, it is a good thing to have a calibration curve for each pasted on a piece of card-board. When making these curves, it will be quite sufficient to take the readings for loads of 10 and 100 grms., and join the two points thus obtained by a straight line.

[2] For experiments on the lever, fine holes about $\frac{1}{32}$ inch in diameter will be required, bored at every fifth centimetre mark. These holes should be on a line with the inside ends of the millimetre division-lines.

headless pin has been fixed, so that when the scale is horizontal the end of the pin is on a line with the top of the scale. This pin will serve as a pointer to show when the scale is horizontal.

A rod supported in this way forms a *lever*, the point at which it is supported (F) being called the *fulcrum*, and the portions of the lever on either side of the fulcrum the *arms* of the lever.

By means of loops of fine cotton, hang a 50-grm. weight on one arm of the lever, and on the other arm a light scale-pan. The scale-pan may be made out of a pill-box, suspended by three threads from a small hook made out of a bent pin.

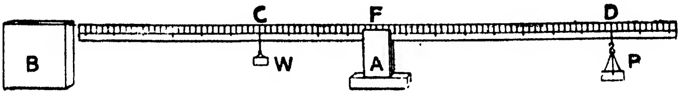

FIG. 41.

Place the 50-grm. weight at a distance of 20 cm. *from the fulcrum*, and the scale-pan at a distance of 40 cm. from the fulcrum. Then put shot into the scale-pan till the lever is in equilibrium, *i.e.* till it becomes horizontal, as shown by the pointer B. Remove and weigh the scale-pan and the shot. Let the weight be P grammes. Then a weight of P grms. at a distance of 40 c.m. *from the fulcrum* has balanced a weight of 50 grms. at a distance of 20 cm. *from the fulcrum.* Keeping the position of the 50-grm. weight unaltered, place the scale-pan successively at distances of 30, 20, and 10 cm. from the fulcrum, and in each case determine the weight which produces equilibrium. Enter your results in a table, as below :—

Left-hand Arm		Right-hand Arm.	
Weight = W.	Distance of W from Fulcrum.	Weight = P.	Distance of P from Fulcrum.

Moments.—Suppose a lever is in equilibrium when a weight, W, is hanging at a distance CF (Fig. 41) from the

fulcrum on one side, and a weight, P, is hanging at a distance, FD, on the other. The earth, attracting the two weights W and P, exerts a force in the vertical direction on the lever at C and D. If, then, we take as our unit of force the force with which the earth attracts a mass of one gramme, or, in other words, if we take the *weight* of a gramme as the unit of force, we shall have a force of W units acting vertically downwards, and therefore at right angles to the lever at C, exactly counterbalancing a force of P units acting downwards and at right angles to the lever at D. The force W tends to turn the lever round the fulcrum B in the opposite direction to that in which the hands of a clock move, or, as it is called, in an anticlockwise direction. The force P, on the other hand, tends to turn the lever in the opposite direction (clockwise), and, as the lever remains horizontal, we see that the tendency of the force W to turn the lever in one direction is exactly counterbalanced by the tendency of the force P to turn the lever in the other direction. The amount of the tendency of a force to turn a lever about a fixed point (the fulcrum) is called the *moment of the force* about that point.

In the previous example, since W remained unaltered throughout, and since it was kept at the same distance from the fulcrum (20 cm.), it is evident that the moment of W about the fulcrum F must have been the same throughout. The value of the force P was changed, as well as the distance of P from the fulcrum ; since, however, in each case the lever was in equilibrium, it follows that the moment of P about the fulcrum F must in each case have been equal to the moment of W about F. Now it will be found that, if each value of P is multiplied by the corresponding distance from the fulcrum, the product is a constant, and that this product is equal to the product of W into its distance from the fulcrum. Therefore the moment of a force, which acts at right angles to a lever, about the fulcrum is obtained by multiplying the force by the distance between the point of the lever at which it acts and the fulcrum.

EXERCISE 57.—*Moments.*

Apparatus as in previous exercise.

Calculate the moments of the forces P and W about the fulcrum for the values obtained in Exercise 56, and hence show that the moment of P about the fulcrum is in each case equal to the moment of W about the fulcrum, so that the condition for equilibrium of the lever is

$$W \times CF = P \times FD.$$

By the above formula calculate the position in which W (50 grms.) must be placed, so that when the scale-pan is at 40 cm. from the fulcrum the weight of the scale-pan and shot may be 25 grms. Test the accuracy of your calculation by making the experiment, placing W at the distance obtained by calculation, the pan at 40 cm., and adding shot till the lever is horizontal, then weighing the pan and shot.

Find the weight of the given piece of lead by hanging it, by means of a cotton loop, from one arm of the lever, and moving the 50-grm. weight till the lever is horizontal. If d is the distance of the lead from the fulcrum, and l that of the 50-grm. weight, then—

$$(\text{Weight of the body}) \times d = 50 \times l.$$

Repeat the measurement several times, hanging the body at different distances from the fulcrum, and enter your results in a table, as below :—

W.	Distance of W from Fulcrum.	Distance of P from Fulcrum.	Calculated Weight of P.

EXERCISE 58.—*Moments (continued).*

Apparatus as in previous exercise.

On the left-hand arm of the lever hang a 50-grm. weight, W, at a distance of 20 cm. from the fulcrum ; and a 20-grm. weight, X, at a distance of 40 cm. from the fulcrum. Place the scale-pan on the right-hand arm, at a distance of 30 cm. from the fulcrum, and add shot till the lever is horizontal. Weigh the scale-pan and shot, P,

and calculate the moment of P about the fulcrum. Also calculate the moment of the 50-grm. and 20-grm. weights respectively about the fulcrum. Add these two last moments together, and show that their sum is equal to the moment of P.

Repeat, placing W at 28 cm., X at 49 cm., and P at 35 cm.

Also hang three weights at different distances from the fulcrum on the left-hand arm, and in the same way obtain the moment of P when the lever is horizontal. Calculate the sum of the moments of the three weights, and show that this sum is equal to the moment of P.

Enter your results in a table similar to the following, adding three more columns when necessary.

Left-hand Arm.							Right-hand Arm.		
W.	Distance of W from Fulcrum.	Moment of W.	X.	Distance of X from Fulcrum.	Moment of X.	Sum of Moments.	P.	Distance of P from Fulcrum.	Moment of P.

Moment of a Force.—In the previous exercises the forces with which we have been dealing have in each case been due to the attraction of the earth. Since this attraction is always exercised in a vertical direction, and the lever has always been brought into a horizontal position, the direction in which the forces have been acting has always been at right angles to the length of the lever; and we have found that, under these circumstances, the product of the force into the distance between the point on the lever at which the force is applied and the fulcrum gives the moment of the force about the fulcrum. We have now to investigate what takes place when the direction of the force is not at right angles to the lever, and to determine how the moment of such a force is to be measured.

For this purpose we shall make use of two spring balances similar to the one calibrated in Exercise 54.

EXERCISE 59.—*The lever, when the directions of the applied forces are inclined to the length of the lever.*

Apparatus:—Two spring balances; box-wood metre scale; piece of narrow-bore glass tube, about $\frac{1}{8}$ inch long; cartridge paper; set square.

Pin a large sheet of cartridge paper down on the table or on a large drawing-board, and, about an inch inside the middle of the top edge, carefully drive a stout sewing-needle upright into the table. Over this needle thread a piece of narrow glass tube (A, Fig. 42) about $\frac{1}{8}$ inch long, and then place the metre scale on the top, so that the needle passes through the hole[1] at the 50-cm. division. The metre scale will then form a lever moving in a horizontal plane about the needle as a fulcrum. Holding the metre scale fixed, and as nearly as possible parallel to the edge of the paper, draw a line on the paper along the edge of the scale. At 30 cm. on each side of the fulcrum draw, by means of a set square, a line at right angles to the line just drawn.

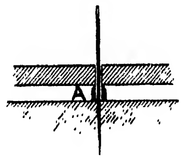

FIG. 42.

Attach the hooks on the end of the strings fastened to the springs of the balances to two small pegs, placed in the holes drilled in the metre scale at 30 cm. on either side of the fulcrum. Then, holding the lever parallel to the line by means of a block of wood or a pin driven into the table, stretch one of the spring balances till the index is about halfway down the scale, and so arrange the balance that the edge of its scale and the thread attached to the spring both lie exactly over the line drawn perpendicular to the lever (AC, Fig. 43). Fix the spring balance in this position by means of a lead weight or by forcing the needle points on the under side into the table. Take away the block or pin used to fix the lever, and in the same way adjust the second spring balance parallel to the other line, moving it away from the lever, and so stretching the spring till the edge of the lever comes back to its original position—that is, till the edge lies exactly over the line drawn on the paper.

[1] In order that the scale may balance well, this hole ought to be at the middle of the scale, and not near the graduated edge as was the hole used in Exercise 56.

The lever is now acted on by two forces, each, as in the previous exercises, at right angles to the lever. Take the readings of the two balances, and by means of the calibration curves obtain the magnitude of the forces, and show that the moments about the fulcrum are equal.

Next, keeping the left-hand balance fixed, move the right-hand balance into some position such as that shown at DB, Fig. 43, adjusting the position of the balance so that (1) the lever comes back to the original position, and (2) the thread lies exactly along the edge of the graduated scale; when this is so, the edge of the scale will point directly at the place where the thread is attached to the lever. A careful study of Fig. 43 will help to make the arrangement clear.

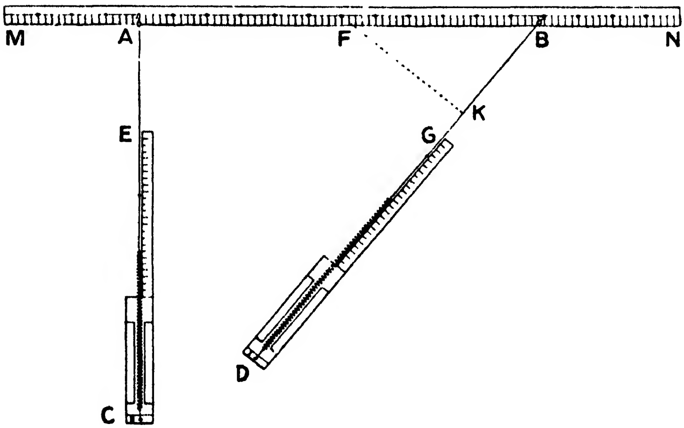

Fig. 43.

In this figure, MN is the metre scale pivoted at F, and acted on by two forces, one along AC, due to the stretching of the spring of the balance CE, and the other along BD, due to the stretching of the spring of the balance DG.

Take the readings on the two balances, and run a pencil along the edge of the scale of the balance DG. Then remove the balance, and produce this line to B; also draw a line, FK, from the fulcrum F perpendicular to GB, and measure the distance FK—that is, the perpendicular distance between the fulcrum and the direction of the force acting at B. Multiply this perpendicular distance by the magnitude of the force, and it will be found that the product is equal to the moment of the force due to the other balance acting at A.

Hence it follows that the moment of a force about a point is equal to the product of the force into the perpendicular distance between the point and the direction or line of action of the force.

Repeat the experiment, keeping the left-hand balance unaltered, and taking the right-hand balance inclined at different angles to the lever, also taking the point of application B at different distances from the fulcrum. Enter your results in a table, as in the following example :—

Left-hand Arm.			Right-hand Arm.		
Force = W.	Perpendicular Distance between Fulcrum and Direction of W.	Moment of W.	Force = P.	Perpendicular Distance between Fulcrum and Direction of P.	Moment of P.
68 grms.	30 cm.	2040	92 grms.	22·2 cm.	2042

The Balance.—The balance is really simply a lever in which the arms are of equal length; the length of the arm being the distance between the centre knife edge and the end knife edge. After the experiments which have already been made, it will be evident that the weight of a body, and hence the mass, will only be equal to the weight and mass of the weights employed to counterbalance it if the two arms of the balance are of exactly equal length. It is therefore important to test a balance to see whether the arms fulfil this condition.

Exercise 60.—*To test the equality in the length of the arms of a balance.*

Apparatus :—Balance; weights; shot; watch-glasses.

Carefully adjust the balance by moving the small nuts fixed to the end of the beam till the pointer comes to rest exactly at the centre of the scale. Then place 100 grms. in the left-hand pan, and a large watch-glass in the right-hand pan. Add shot and tinfoil to the watch-glass till the pointer is again brought back to the zero. Set the watch-glass and its contents aside, being careful not to spill any of the shot. Perform the same operation with a second watch-glass. Now remove the weights and place the first watch-glass in the left-hand pan: if the pointer does not come to zero, add weights

to the lighter pan till it does, and let the weights thus added be x grammes.

The two watch-glasses are of exactly equal weight, since, when placed one after the other in the *same* pan, they have counterbalanced the same weights, and they each weigh very nearly 100 grms. Let a and b be the lengths of the arms of the balance, a being the shorter, so that the weights x have been added to the pan attached to the arm a. Then, by the principle of moments (p. 72),

$$(100 + x)a = 100 \times b$$

$$\therefore \frac{a}{b} = \frac{100}{100 + x}$$

So that the ratio of the lengths of the arms of the balance is $\frac{100}{100 + x}$, the shorter arm being on the side on which the weight x has been added.

Repeat the experiment, making the weight of the watch-glasses 80 grms. each.

Rider.—The principle of the lever is made use of in very delicate balances, to avoid the necessity of using very small weights, such as milligrammes and fractions of a milligramme, which, on account of their very small size, would be difficult to handle. The smallest weight ordinarily used is a centigramme (·01 grm.). Now, a centigramme weight, when placed in the right-hand pan, will counterbalance a centigramme placed in the other pan. If, however, the centigramme weight, instead of being placed in the pan, were hung on the *beam* of the balance halfway between the middle and end knife edges, it would produce the same turning moment as a weight of half a centigramme, or 5 milligrammes, placed in the pan, *i.e.* at twice the distance from the fulcrum. In the same way, when hung on the beam at a distance of one-tenth of the length of the arm of the balance from the central knife edge, the centigramme will only produce the same effect as one milligramme (*i.e.* one-tenth of 1 cg.) placed in the pan. Thus, instead of having separate weights for the purpose, the milligrammes and fractions of a milligramme are obtained by sliding a piece of wire having a mass of 0·01 grm., etc., called a *rider* (Fig. 44),

along the beam, which is graduated so that the position of the rider can be read off.

EXERCISE 61.—*Use of a rider.*

Apparatus:—Chemical balance with divided beam; set of gramme weights and centigramme rider; pieces of metal.

The balance with which you are provided for this exercise is more sensitive than the one shown in Fig. 12, and is intended for determining the mass of a small body to within one-tenth of a milligramme. Being careful to observe the rules given on p. 22, add weights to the right-hand pan of the balance till the addition of another centigramme would cause the right-hand pan to be the heavier. Then close the glass front of the balance case, and move the rider by means of the sliding arm provided for the purpose, till the balance is in exact equilibrium. Read off the mass of the weights in the pan, which will give the mass of the body to the nearest centigramme; and obtain the milligrammes and tenths of a milligramme from the position of the rider.

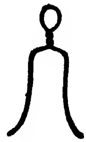
FIG. 44.

Measurement of Angles.—In the subsequent exercises, it will often be necessary to measure the inclination of one line to another, or the angle included between two lines. The unit commonly employed for measuring angles is called a degree, and is the ninetieth of a right angle. Each degree is subdivided into 60 minutes, and each minute into 60 seconds. It is usual to indicate degrees, minutes, and seconds by the symbols °, ′, ″ respectively; thus an angle of 2 degrees, 34 minutes, 21 seconds, would be written $2^\circ\ 34'\ 21''$.

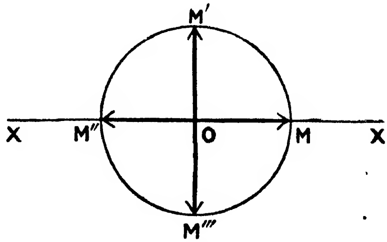

FIG. 45.

Suppose we take a rod (OM, Fig. 45), pivoted at one end, O, and (starting with it lying along the line X′X) turn it in an anti-clockwise direction (p. 72): then, when the rod reaches

the position OM′, it will have been turned through an angle of 90°; if we continue turning the rod then, when it reaches the position OM″, it will have been turned through an angle of 180°. The rod now again lies in the line X′X, but it will be seen that, while at first the arrow at the end of the rod pointed to the right, it now points to the left, and thus a rotation of the rod through an angle of 180° is equivalent to turning it end for end. Continuing the turning, when the rod reaches the position OM‴ it will have turned through an angle of 270°; and when it arrives back in its original position, OM, it will have turned through 360°.

EXERCISE 62.—*Measurement of angles with the protractor.*

Apparatus:—Protractor;[1] card with three lettered triangles (equilateral, isosceles, scalene); pencil, paper and ruler.

The protractor with which you are supplied, consists of a semi-circular piece of cardboard (ABC, Fig. 46) with the degrees marked round the curved edge. The centre of the circle of which the curved edge is a part is at the point O, where the line BO cuts the straight edge of the protractor.

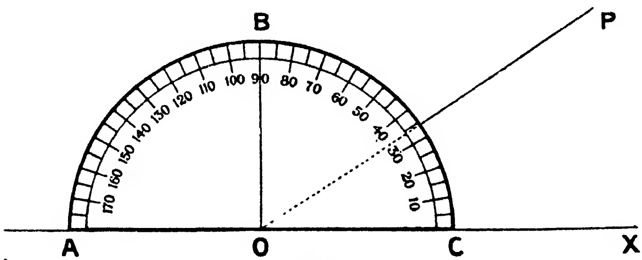

FIG. 46.

Draw on a sheet of paper two lines OX, OP, inclined to one another, and meeting at O. To measure the angle XOP included between the lines OX, OP, place the protractor in the position shown in the figure with the centre over the point O, and the straight edge AC along the line OX. Then the reading on the circular edge where it is cut by the line OP gives the angle between OX and OP.

[1] Suitable protractors can be obtained made of celluloid, or can be made out of thin millboard by cutting a divided circle, 6 inches in diameter, in two.

Measure in this way each of the angles of the three triangles supplied to you. For each triangle add the three angles together, and see if you can find any general rule for giving the value of the sum of the three angles of any triangle.

If you are required to draw two lines inclined at a given angle, say 45 degrees: draw any straight line, and take some point, O, on it. Place the protractor with its centre at O, and its straight edge lying along the line. Then, with a pin, prick a hole in the paper exactly opposite the end of the 45° division line. Remove the protractor, and join O to the pin-hole. The two lines thus obtained will be inclined at an angle of 45°. Draw straight lines inclined to one another at the following angles :—30°, 60°, 90°, 120°, 240°.

The Graphic Representation of Forces.—In order to completely define a force acting on a body, we require to know three things: (1) the point at which the force acts, or the point of application of the force; (2) the direction in which the force acts, and (3) the magnitude of the force. Thus, in the case of the force exerted by the spring balance DG (Fig. 43) on the lever, the point of application of the force is at B, where the string is attached to the lever, the direction in which the force acts is along this string and towards the spring, while the magnitude of the force is given by the reading on the scale of the spring balance.

If from the point of application of a force we draw a straight line in the direction in which the force acts, and if we make this line as many units of length long as there are units of force in the given force, then this straight line will *completely* represent the given force.

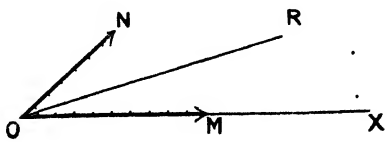

Fig. 47.

If at the point O (Fig. 47), there is a force of 10 units acting in the direction OX; then, taking 1 cm. to represent a unit of force, the line OM will represent the force. In order to indicate that the force is acting from O to M, and not from M to O, an arrow-head is usually placed at the end of the line representing the force, pointing in the direction in which the force

is acting. Now, suppose that in addition to the force OM there is another force, ON, of 7 units also acting at O, so that the angle NOM is 45°. The force OM tends to move the point O in the direction OM, while the force ON tends to move the point O in the direction ON; hence, when both the forces act simultaneously, since the point O cannot move in two directions at the same time, if O were free it would move, under the influence of the *two* forces, in some direction between OM and ON. Let OR be this direction. A force acting along OR would also move the point O in the direction OR, so that by taking this force OR of a suitable magnitude we could arrange that it should produce when acting alone the same effect as is produced by the two forces OM, ON acting together. This force which would produce the same effect on O as the two forces OM, ON is called *the resultant* of the two forces.

Let OR (Fig. 48) represent the resultant of the two forces OM, ON, so that if the line RO is produced to R′, OR′ being equal to OR: then OR′ will represent a force acting at O equal in magnitude to OR, but acting in an opposite direction. Hence the two forces OR, OR′ exactly neutralize each other, or are in equilibrium. But by supposition OR produces the same effect as OM and ON, therefore the three forces OM, ON, OR′ will be in equilibrium. In order, then, to find by experiment the resultant of two given forces, we find a third force, OR′, which, together with the two given forces OM, ON, produces equilibrium, then the resultant of the two given forces is equal in magnitude, but opposite in direction to this force OR′.

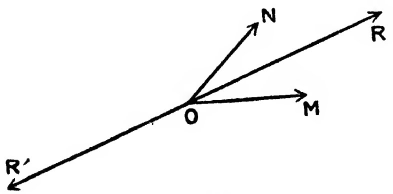

FIG. 48.

EXERCISE 63.—*To find the resultant of two forces acting at a point.*

Apparatus:—Three spring balances; cartridge paper; protractor.

You are required to find the resultant of two forces of 76 and 40 units respectively, acting at a point, and inclined at an angle of 60° to each other.

Pin a sheet of cartridge paper down on the top of the table, and on it draw two lines about 10 inches long, inclined at an angle of 60°, and meeting at a point O. Then fasten the hooks attached to the ends of the threads of three spring balances to a small ring, about one-tenth of an inch in diameter, made by bending a pin. Pass a pin through this ring, and drive it upright into the table at the

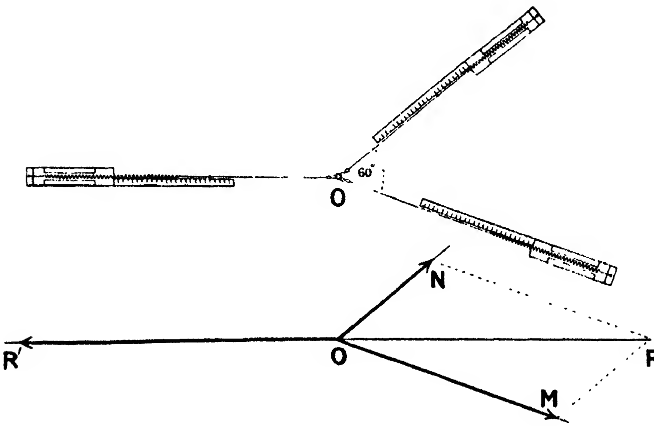

FIG. 49.

point where the two lines, inclined at 60°, meet. Set one of the spring balances so that the edge of the scale and the thread lie vertically over one of these lines, and the index is opposite the graduation,[1] which corresponds to a stretching force of 76 grms. Fix the balance in this position. Adjust another of the balances along the other line, so that its reading corresponds to a stretching force of 40 grms. You now have two forces of 40 and 76 units respectively, inclined at an angle of 60°, acting on the pin. Remove this pin, and then by trial find a position for the third balance, such that the ring again lies exactly over the point where the two lines, inclined at 60°, meet. Take the reading on the third spring balance, and draw a line along the edge of the graduated scale, which ought (if the balance has been properly adjusted) when produced to pass

[1] Found from the calibration curve (p. 69).

through the point of intersection of the other lines. The direction of the resultant of the two forces is along this line OR (Fig. 49), and the magnitude of the resultant is given by the reading on the balance. From O measure off the lengths OM, ON, OR, proportional to the two forces and the resultant. A convenient scale to adopt, is to take one centimetre to represent a force equal to the weight of 5 grms. The three lines OM, ON, and OR will now represent in magnitude and direction the two given forces and the resultant. Through the two points M and N draw lines MR″ and NR″ parallel to ON and OM respectively, meeting at the point R″. If the experiment has been carefully performed, it will be found that R″ and R are the same point. From this we see that, to graphically obtain the resultant of two forces acting at a point, straight lines must be drawn through the extremities of the straight lines representing the forces, so as to form with these lines a parallelogram. Then the diagonal of this parallelogram drawn through the point of application of the forces will represent the resultant both in magnitude and direction. This proposition is called the *parallelogram of forces.*

Find by experiment the resultant of the following pairs of forces, and check your results by constructing the parallelogram of forces, and measuring the diagonal.

First Force.	Second Force.	Angle included between the Directions of the Forces.
50 grms.	40 grms.	30°
60 ,,	20 ,,	60°
40 ,,	75 ,,	45°
50 ,,	50 ,,	90°
80 ,,	80 ,,	120°

Triangle of Forces.—If three forces acting at a point can be represented in magnitude and way of action by the three sides of a triangle taken in order, they will be in equilibrium.

Let ABC (Fig. 50) be a triangle; from a point, O, draw three straight lines: OP parallel and equal to AB, OQ parallel and equal to BC, and OR parallel and equal to CA. Then the above enunciation states that the three forces represented by OP, OQ, and OR will be in equilibrium. This proposition is called the *triangle of forces.*

Exercise 64.—*Triangle of forces.*

Apparatus as in previous exercise.

Pin a sheet of cartridge paper down on the top of the table, and on it draw any triangle ABC.[1] Measure the lengths of the sides of this triangle.

Through any point, O, on the paper draw a line, OP, parallel to AB, and in the same direction as AB; that is, the direction from O to P is the same as the direction from A to B. Also draw lines OQ, OR parallel to and in the same direction as BC and CA respectively. Then pass a pin through the ring attached to three spring balances, as in the last exercise, and fix this pin into the table at O. Adjust the three spring balances along the three lines OP, OQ, and OR, so that the readings on their scales are equal to

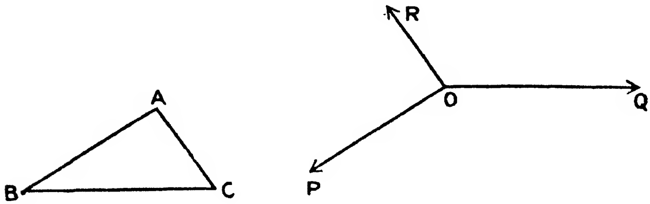

Fig. 50.

the forces represented by the lengths of the corresponding sides of the triangle respectively. Thus the reading on the balance lying along OP must be equal to the force represented by the side AB, and so on. You have now three forces acting on the ring attached to the balances, which are represented in magnitude and direction, or way of action, by the three sides of the triangle ABC. If, then, the triangle of forces is true, these forces ought to be in equilibrium. To test this, remove the pin which has held the ring fixed; if the ring does not move, it means that the forces are in equilibrium.

Repeat the experiment for triangles of various shapes.

Also show that the proposition holds for each pair of forces and their resultant reversed in direction which were found to give equilibrium in Exercise 63.

[1] If 1 cm. is going to be taken to represent a force equal to the weight of 5 grms., then, since the spring balances only measure up to 100 grms., it is necessary that the longest side of this triangle should be less than 20 cm.

EXERCISE 65.—*Resultant of two parallel forces, when the forces act in the same direction.*

Apparatus:—Balance; metre scale, etc., used in Exercise 56.

Suspend the metre scale used as a lever in Exercise 56 from the stirrup carrying the left-hand pan of the balance, by means of a needle passing through the hole made at the 50 cm. division, and a double loop of cotton, in the manner shown in Fig. 52. To make such a double loop, (1) double about 6 inches of the cotton back on itself, as at A, Fig. 51; (2) again double back this portion, B; (3) treating these four strands of cotton as a single string, tie a single knot, C, as far from the end as possible. The finished knot, opened out, is shown at D. Such a double knot will be frequently required when it is necessary to suspend a rod-shaped body from a single thread.

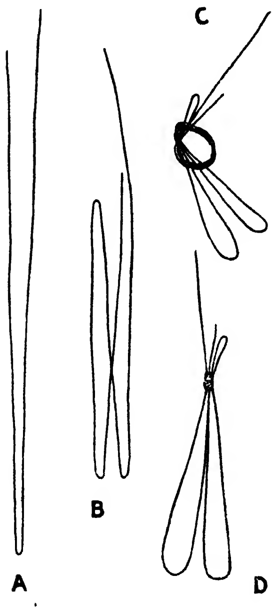

FIG. 51.

The reason the cotton at the top is not simply looped over the hook which carries the stirrup for the scale-pan is, that if this is done, one is very liable to pull the balance beam right over, while in the arrangement adopted the scale-pan resting on the base of the balance prevents this happening.

Place shot in the right-hand pan of the balance till the weight of the lever is exactly counterpoised. Then hang a 20-grm. weight by a loop of cotton at a distance of 30 cm. from the fulcrum. The fulcrum, as before, is the needle, but, instead of being supported on wooden blocks, it is in this case hung by a thread. On the other arm of the lever, and at a distance of 40 cm. from the fulcrum, hang the small scale-pan used in Exercise 56, and add shot till the lever is in equilibrium, *i.e.* horizontal. A pin fixed in a block of wood can, as before, be used as an index to show when the lever is horizontal.

Leaving the 20-grm. weight and the scale-pan containing the shot in place, add weights to the right-hand pan of the balance till

the lever is again counterpoised. Let these added weights be R. Then, since the weight of the lever alone was counterpoised by the shot previously placed in the balance-pan, the weight R represents the additional downward pull on the left-hand arm of the balance due to the 20-grm. weight, and the scale-pan and shot which are now hung from the lever. Remove the scale-pan and shot, and weigh ; let the weight be P grms.

Then the resultant of the two parallel forces due to the 20-grm. weight, which we may call W, and the weight P must pass through the fulcrum or the lever would not be in equilibrium. For the

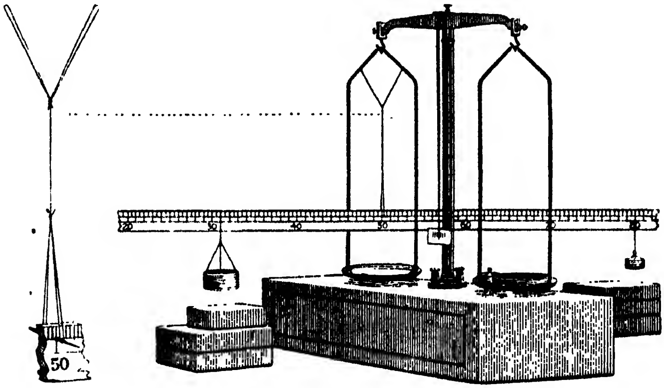

FIG. 52.

meaning of the word "resultant" is, that if we replaced the two forces P and W by the resultant, the equilibrium of the body on which the two forces are acting, in this case the lever, would remain unaltered. But the only place at which we can apply a downward force to the lever, after removing P and W, without upsetting the equilibrium, is at the fulcrum. Hence the direction of the resultant of P and W must pass through the fulcrum ; the direction of the resultant is vertically downwards, and its magnitude is R.

If AB is the distance of P from the fulcrum, or the distance between the point of application of the force P and the resultant R, and BC is the distance of W from the fulcrum, then from your results show that the two following relations hold :—

$$P \times AB = W \times BC$$
$$P + W = R.$$

Repeat the experiment, setting the 20-grm. weight (W) at different

distances from the fulcrum, and, keeping the value of P the same (*i.e.* not altering the quantity of shot in the scale-pan), show that the first of the above relations holds; compare p. 73; also show that R is constant.

Repeat the experiment with different values for P, by using different quantities of shot in the scale-pan. Enter your results in either case in a table as below:—

P.	AB.	P × AB.	W.	BC.	W × BC.	P + W.	R.

Centre of Gravity, or Mass Centre.—In the previous exercise we have seen that, if there are two parallel forces, P and W, acting at A and C (Fig. 53), then they produce the same effect as a single force equal to P + W acting at a point B, such that P × AB = W × BC. If there is a third parallel force, Q, acting at D, then we can suppose the forces P and W replaced by their resultant P + W acting at B, and then we have two parallel forces—one a force, P + W, acting at B, and the other a force, Q, acting at D. The resultant of these two forces will be a force of P + W + Q, acting at a point, E, such that (P + W) × BE = Q × ED.

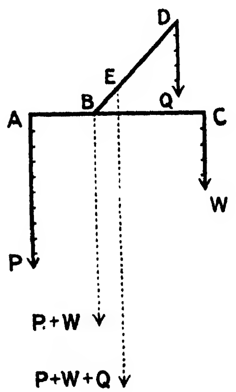

FIG. 53.

We might in this way proceed for any number of parallel forces, and obtain in every case a single force which would be the resultant of all the parallel forces.

Now, a body may be considered as made up of a very large number of small particles, each of these particles being pulled downwards by the attraction of the earth. Thus we have a number of parallel forces, and the sum of all these forces is

what we call the weight of the body. From what has been said above about the resultant of a number of parallel forces, it will be evident that there is a single resultant to all these parallel forces. Independent proof of this fact is obtained when we suspend a body by a *single* string, for in this case the only upward force is the pull of the string acting vertically upwards, and this single force must, if the body is in equilibrium, be equal and opposite to the resultant of all the parallel forces which make up the weight of the body.

It is found that, not only is there a single resultant of all the downward parallel forces due to the attraction of the earth on the particles of a body, but that this resultant passes through a certain fixed point, no matter what the position of the body may be. This point is called the *centre of gravity* or *mass centre* of the body.

EXERCISE 66.—*To find the centre of gravity of a flat sheet of cardboard.*

Apparatus :—Piece of thick cardboard ; plumb-bob ; cotton.

Make a neat round hole with a large pin near the edge of the sheet of cardboard supplied to you, and hang it from a fine pin passed through this hole and fixed horizontally into the edge of the table, so that the sheet of card can swing freely.

When the card is at rest the resultant of all the forces acting on the particles of which the card is composed must pass through the pin, because the only upward force acting and keeping the body in equilibrium is the upward pressure of the pin on the top of the hole in the card. Since the resultant force due to the weight of the body must act vertically downwards, if we draw a vertical line on the card through the centre of the pin, this line will represent the direction of the resultant when the card is in this position. In order to draw this vertical line, hang a small metal ball by a piece of cotton from the pin, forming a *plumb-line*, and mark on the lower edge of the card where the plumb-line cuts this edge. As it is difficult to make such a mark without interfering with the hang of the card and plumb-line, having noted the approximate position of the place where the plumb-line cuts the lower edge, make a series of marks along the edge about 1 mm. apart, thus forming a small scale. Then note exactly where the plumb-line cuts this scale, being particularly careful to let the plumb-line hang quite close to

the surface of the card, and to place the eye in a line passing through the plumb-line, and perpendicular to the surface of the card, for a similar reason to that discussed with reference to the measurement of a length with a scale (p. 5). Remove the card from the pin, and with a sharp-pointed pencil draw a line on the surface of the card joining the point where the plumb-line cuts the lower edge of the card and the centre of the pin-hole.

Repeat the process, hanging the card from four or five different points, in each case drawing a line on the surface of the card to indicate the position of the plumb-line. It will be found that all these lines intersect at a single point. If the card had no thickness this point of intersection would be the centre of gravity. As the card has thickness, the centre of gravity is, if the card is quite flat and uniform, immediately beneath this point and halfway between the front and back surfaces. Support the card on the point of a pin placed at the point of intersection of the lines; it will be found that the card balances in a horizontal position, showing that the centre of gravity is immediately above the point of the pin.

EXERCISE 67.—*To find the centre of gravity of a sheet of cardboard by balancing.*

Take the sheet of cardboard used in the previous exercise, and, laying it flat on the table with the side on which the lines were drawn in the previous exercise uppermost, carefully push it over the edge of the table till it just balances on the edge. Hold the card in this position, and draw a sharp-pointed pencil along the under surface of the card, using the edge of the table as a ruler. When the card balances on the edge, the centre of gravity must lie vertically over the edge; for the weight of the card, which by definition acts through the centre of gravity, must act in a direction passing through the edge, otherwise the weight would have a moment (see p. 72) round the edge and cause the card to turn. Now turn the card into some other position, and repeat the experiment. The point where the two lines obtained intersect will be the centre of gravity; for, by what has just been said, the centre of gravity must lie in both the lines. Repeat with the card in two or three other positions, and show that all the lines pass through a single point. Pass a pin through the card, and see how the point thus found agrees with that found in the previous exercise.

EXERCISE 68.—*Centre of gravity of a triangular lamina.*[1]

Apparatus:—Cardboard; plumb-bob.

From a sheet of cardboard cut out a triangle of about the shape of ABC (Fig. 54), and such that the side AB is about 8 inches long. Determine the centre of gravity of this triangle by the method used in Exercise 66.

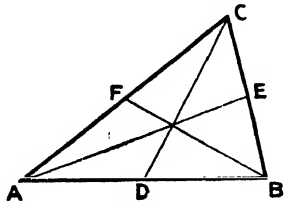

FIG. 54.

Bisect the sides of the triangle at the points D, E, and F, and join the points of bisection to the opposite angles. It will be found that these three lines meet in a point, and that this point is the centre of gravity previously found by experiment. Hence, write out a rule for finding geometrically the centre of gravity of a triangle, and illustrate by applying it to an example.

Heavy Lever when the Fulcrum is not in the Vertical through the Centre of Gravity.—In the previous exercises where a lever has been employed, the fulcrum has always been so placed that the weight of the lever, acting at the centre of gravity, has not produced a turning moment. We now have to consider the case when the centre of gravity of the lever is on one side of the fulcrum. Let the centre of gravity of the lever AB (Fig. 55) be at C, while the fulcrum

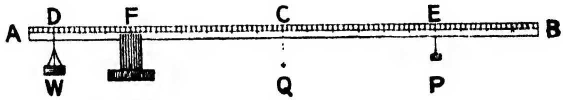

FIG. 55.

is at F. If Q is the weight of the lever, which may be supposed to act at the centre of gravity C, then the turning moment round the fulcrum F due to the weight of the lever is Q × FC. If the lever is in equilibrium under the action of the two forces

[1] A lamina is a flat body in which the thickness is very small compared to the length and breadth.

W and P, applied at D and E respectively, then $W \times DF = Q \times FC + P \times EF$; since, if there is equilibrium, the moment of the force W about the fulcrum F must be equal and opposite to the sum of the moments of P and Q (see p. 74).

EXERCISE 69.—*Lever.*

Apparatus:—As in Exercise 56.

Determine, by actual weighing, the weight (Q) of the metre scale used as a lever in the previous exercises. Then support the lever on two wooden blocks, by means of a needle passed through the hole at 40 cm. from the end. Place about 100 grms. of shot in the scale-pan used in Exercise 56, and weigh; let the weight be W. Hang a 20-grm. weight (P) by means of a loop of cotton on the longer arm, and the scale-pan on the shorter arm.

Set the scale-pan at a distance of 30 cm. from the fulcrum, and move the 20-grm. weight till the lever is horizontal. Calculate the moment of W about F, and the sum of the moments of P and Q about F, and show that these are equal. Repeat, placing W at different distances from the fulcrum, also using different values for W. Again support the lever at different distances from the end, and repeat. Enter your results in a table as below, making a lettered sketch of the arrangement employed.

W.	DF.	W × DF.	Q.	FC.	Q × FC.	P.	FE.	P × FE.	Q × FC + P × FE.

EXERCISE 70.—*Indirect determination of the weight of a lever.*

Apparatus:—As in previous exercise.

Set up the lever as in the previous exercise, with the fulcrum at 10 cm. from one end. Hang the scale-pan from the shorter arm, and as far from the fulcrum as possible, say at 9·5 cm. Place shot in the scale-pan till the lever is horizontal. Remove the scale-pan, and weigh; let the weight be W. Then—

$$W \times 9{\cdot}5 = Q \times 40,$$

where Q is the weight of the lever; since the turning moment of

the weight W is equal to the turning moment of the weight of the lever acting at the centre of gravity which is at the 50 cm. division.

$$\therefore Q = \frac{W \times 9{\cdot}5}{40}$$

Repeat the experiment, supporting the lever at 10, 20, 30, and 40 cm. from the end respectively, and in each case calculate the weight of the lever.

The Inclined Plane.—If a smooth metal cylinder, O (Fig. 56), is supported on an inclined plane, AB, being kept from rolling down the plane by a force, P, acting parallel to the inclined plane, then O is in equilibrium under the action of three forces: (1) the weight of the cylinder acting through the centre of gravity vertically downwards; (2) the force P acting along OP parallel to BA; (3) the reaction Q of the plane which acts at the point where O touches the plane, and at right angles to BA. These three forces, being in equilibrium, can be represented by a triangle having its sides parallel to the three forces. Such a triangle is obtained by producing QO to D, and drawing ED parallel to BA. But the triangle ABC is similar to the triangle EOD; that is, the sides of the triangle ABC are to one another as the sides of the triangle EOD. Hence the three forces P, Q, and W are represented in magnitude by the three sides AC, BC, AB of the triangle ABC. Thus—

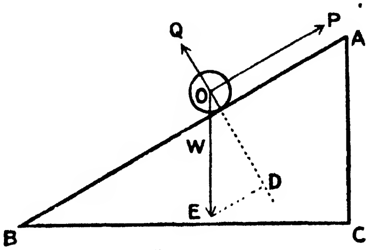

FIG. 56.

$$\frac{P}{W} = \frac{AC}{AB} \text{ or } P \times AB = W \times AC.$$

That is, for a force acting parallel to the inclined plane the ratio of the force to the weight supported on the plane is the same as the ratio of the height to the length of the inclined plane. It will be seen that the force necessary to raise W if an inclined plane is employed is less, in the ratio of the height

to the length, than the force necessary to raise W without any inclined plane, for in this case P would have to be equal to W.

When the force P acts parallel to the base BC of the plane, then, in the same way, we have—

$$\frac{P}{W} = \frac{AC}{BC} \text{ or } P \times BC = W \times AC.$$

EXERCISE 71.—*Inclined plane, power parallel to the length.*

Apparatus :—Inclined plane; spring balance; solid metal cylinder.

You are supplied with an inclined plane, which can be set at different inclinations to the horizontal. At the upper end of the inclined part, one of the spring balances used in the previous exercises can be screwed, as shown in Fig. 57. A solid metal

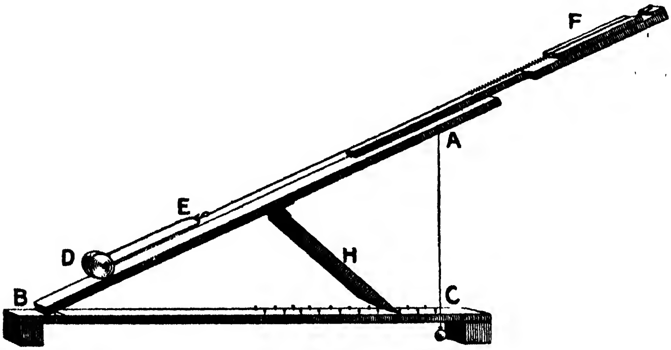

FIG. 57. ($\frac{1}{10}$)

cylinder, about $1\frac{1}{4}$ in. long and $1\frac{1}{4}$ in. in diameter, has a fine steel knitting-needle passing through an axial hole. A U-shaped piece of wire, E, with the ends bent round, serves to connect the cylinder to the spring balance. At a certain number of whole centimetres, say 50 cm., from the hinge, and as near the lower edge as possible, drive a pin, A, into the piece of wood forming the inclined plane. From this pin suspend a small weight by means of a piece of cotton, to act as a plumb-line. Weigh the cylinder D together with the axle and the connecting-piece E; let the weight be W grms. Set the prop H against the pair of nails furthest away from the hinge, so that the plane is inclined at as small an angle as possible. Take

the reading on the spring balance, and measure the distance AC between the top of the base and the under surface of AB, at the place where the plumb-line hangs.

Then the length of the plane is AB and the height AC. The force is obtained from the reading of the spring balance, and W has been determined by weighing. Repeat the experiment for the plane inclined at different angles, and calculate the values of P × AB and W × AC, entering your results in a table as below :—

P.	AB.	P × AB.	W.	AC.	W × AC.

The numbers obtained in the third and sixth columns ought for each inclination to be equal.

EXERCISE 72.—*Inclined plane, power parallel to the base.*

Apparatus as in previous exercise.

To examine the relation between P and W when P acts parallel to the base of the plane, the spring balance is supported on some blocks in a horizontal position, at a height of about 20 cm. above the top of the table. Then move the inclined plane as a whole nearer or further away from the spring balance, till the string EF,

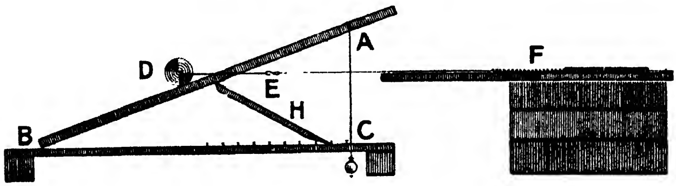

FIG. 58. ($\frac{1}{12}$.)

Fig. 58, is horizontal. When this condition is satisfied, read the spring balance, and measure the distances AC and CB. Then CB is the base, and AC the height, of the inclined plane. The value of P is obtained from the reading of the spring balance, and W is known. Repeat the experiment for different inclinations of AB, and calculate the values of P × BC and W × AC, entering your results in a table similar to that used in the last exercise. The values of these products ought to be equal for each inclination.

The Pulley.—The most usual way of exerting a force in a given direction, is to employ for this purpose the tension of a flexible string, for the tension always acts in the direction of the length of the string. The easiest way of obtaining a tension of a given amount in a string is by attaching a weight, but in this case the tension always acts vertically downwards. Suppose, however, we required a force acting, say, vertically upwards, we might obtain such a force by passing a string over a smooth peg, and attaching a weight to the end. It would, however, be found that the weight which it was necessary to hang at one end to obtain an upward force of, say, 1 kilo., would, on account of the friction of the string against the peg, be much greater than 1 kilo. In order to reduce this friction when a string is made use of in this way to alter the direction of a force, what are called *pulleys* are employed. A pulley consists of a circular disc called the *sheaf*, the outer edge of which is often grooved, and of a framework called the *block*, carrying an axle on which the sheaf turns.

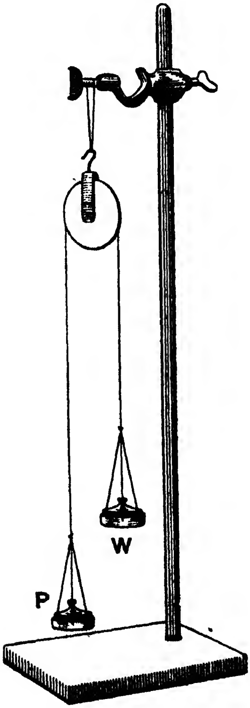

Fig. 59.

Exercise 73.—*The fixed pulley.*

Apparatus:—Small pulley, about 3 in. in diameter; two scale-pans; weights.

Hang the small pulley supplied to you from a retort-stand (Fig. 59). Pass some strong thread over the sheaf, and to either end attach a scale-pan, the weight of which has been made equal to some whole number of grammes, say 5 or 10, by the addition of tin-foil. Put weights in one of the scale-pans (W) so as to make, together with the weight of the pan, 20 grms. Add shot or weights to the pan P, till it is just able to draw up the weight W.

Determine the weight of P. Repeat, making W, in succession, 40, 60, 80, 100, grms., and enter your results in two columns, putting the values of W in one, and those of P in the other. It will be found that in every case P is greater than W. The difference P – W represents the weight which has to be added to P, in order to overcome the friction of the pulley on its axle. It may be reduced by making the diameter of the sheaf very large, and the axle very fine, and supporting it so as to diminish the friction as much as possible.

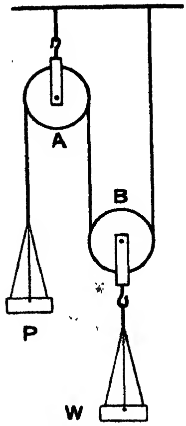

FIG. 60.

EXERCISE 74.—*A single movable pulley.*

Apparatus:—Same as in previous exercise, with the addition of a second pulley.

Arrange two pulleys in the manner shown in Fig. 60—one, A, being fixed, and the other, B, movable. Place a 50 grm. weight in the pan W attached to the movable pulley, and find the weight P which must be added to the other pan, so as just to raise W. This may either be done by adding "weights" to P, or by adding shot, and then weighing on a balance. Determine in the same way the values of P when 100, 150, and 200 grms. are added to W. Then remove B and its attached scale-pan, and weigh. This weight, added to the weight placed in the pan, will give the weight raised by P in each case. Draw up a table as below, and fill in the different columns.

W.			P.	2P.	2P – W.
Weight of Scale-pan and Pulley.	Added Weight.	Total.			

It will be found that 2P is always a little greater than W, and that the difference 2P – W is about twice as great as the difference

found between P and W in the last exercise. Since in this case we are dealing with two pulleys, we should expect friction to have twice the effect it had in the previous case, and we may conclude that the cause of the difference found between 2P and W is the friction of the two pulleys, and that, if it were not for this friction, P would be half W. Hence, by using a movable pulley in this way, we can raise a weight twice as great as we could lift without the pulley.

Place the bottom of the scale-pan W in contact with the top of the table, and measure the height of the bottom of P above the table. Then raise W through a distance of 10 cm., and again measure the distance of P from the table. It will be found that P has moved down through 20 cm. Thus, although when P is equal to half W it is capable of raising W, in doing this it has to move down through twice the height through which it raises W.

Time.—The unit of time employed for scientific purposes, and which will be used in this book, is the second. The second is $\frac{1}{86400}$ part of a mean solar day. Since the time which elapses between the passage of the sun over the meridian (*i.e.* noon) on one day to the passage on the next day, or, in other words, the length of a day,[1] varies during the year, the mean of all the intervals of time between noon on one day and noon on the next for the whole year is taken, and this interval is called a mean solar day. Each day is divided into 24 hours, each hour into 60 minutes, and each minute into 60 seconds. In order to prevent confusion between minutes and seconds of time, and minutes and seconds of angle (see p. 79), it is usual to indicate hours, minutes, and seconds of time by the letters h., m., and s., respectively.

EXERCISE 75.—*Simple pendulum.*

Apparatus:—Metronome ticking seconds; lead plumb-bob; retort-stand, and clamp; two small pieces of wood.

You are supplied with a metronome, which is a piece of clockwork with a governing mechanism so that it can be made to tick once every second. The ticks of the metronome are very loud and distinct, so that they can be heard even at some distance. Hang the lead plumb-bob by a length of fine cotton from two blocks of

[1] The term "day" is here used to include the whole 24 hours, not simply the part of the 24 hours during which it is light.

wood held in a retort clamp, shown at A (Fig. 61), so as to form a pendulum. The object of suspending the pendulum in this way is that if the cotton is simply wound round a rod, B (Fig. 61), then, when the pendulum is in the position CD, the length of the suspending thread is greater than when the pendulum is in the position EF. Place the retort-stand with the clamp projecting over the edge of the table, and adjust the length of the thread so that the pendulum bob just clears the floor. Bring the pendulum to rest, and draw a chalk line on the floor, at right angles to the edge of the table and immediately below the bob. Draw the bob about 6 inches on one side, so that it will swing parallel to the edge of the table, and let it go. The pendulum will swing from side to side, crossing and recrossing the chalk mark which indicated its position when at rest. Such a movement as this is called an *oscillatory* movement, and the swing of the pendulum from the extreme position on either side back to its extreme position on the *same* side is called one oscillation. The distance between either of the extreme positions and the position of rest is called the *amplitude* of the oscillation. Allow the pendulum to swing, and notice that the amplitude gradually decreases. Find how much the amplitude decreases during fifty oscillations. Measure the distance between the top of the plumb-bob and the point of support, *i.e.* the lower face of the pieces of wood holding the thread. Also measure the diameter of the plumb-bob, and add half this length to the length of the thread, and thus obtain the distance between the centre of gravity of the plumb-bob and the point of support. This distance is called the length of the pendulum. Again set the pendulum swinging, so that the amplitude is about 4 inches. Then let one observer watch the pendulum, and when the bob crosses the chalk-mark exactly at a tick of the metronome let him rap sharply on the table. Let him count about thirty of the oscillations of the pendulum, continuing to count till the bob again crosses the chalk-mark, in the same direction as before, exactly on a tick; when this occurs he must again rap on the table, and immediately make a note of the number of oscillations, and then again note the amplitude. A second observer must start counting the ticks of the metronome at the first rap, and continue counting till the second rap, thus obtaining the time the

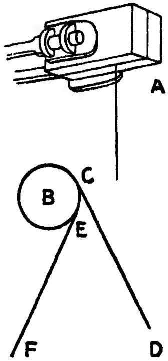

FIG. 61.

pendulum took to make the number of oscillations counted by the first observer. Divide the number of oscillations into the time, and thus obtain the time of one oscillation. Repeat the experiment, starting in turn with amplitudes of 6, 8, 10, and 12 inches respectively, entering your results in a table, as below :—

Number of Oscillations.	Time.	Time of one Oscillation.	Amplitude.	
			At start.	At finish.

It will be noticed that, although the distance through which the pendulum bob has moved has been very different in the above experiments, nevertheless the time taken to make one oscillation has remained the same. Thus, when the amplitude of motion of a pendulum is not greater than those employed above, we may employ such a pendulum to measure time, since the time of an oscillation does not alter as the amplitude alters.

EXERCISE 76.—*Simple pendulum.*

Apparatus as in previous exercise.

As in the previous exercise, determine the time of oscillation and the corresponding lengths for pendulums of approximately the following lengths :—120, 100, 80, 60, 40, 30, 20, 15, 10, 7, and 5 cm. In the case of the shorter lengths it will be necessary to take the time of from 50 to 100 oscillations in order to obtain the time of oscillation with any degree of accuracy. Calculate the square of the lengths, and divide by the corresponding times for one oscillation and observe that the quotient is constant: showing that the time of oscillation of a simple pendulum varies as the square of the length, so that a pendulum 2 feet long takes four times as long to make an oscillation as one 1 foot long. Also plot your results on a sheet of curve paper, taking the lengths of the pendulum as abscissæ and the corresponding times of one oscillation as ordinates. Draw a curve evenly through the points, and from this curve

determine the length of the pendulum which would make one oscillation in two seconds. Since such a pendulum will pass through its point of rest once every second, it is called a "seconds pendulum." Test the accuracy of your determination by setting up a pendulum of the length you have found, and seeing that it *keeps* "in step" with the metronome.

EXERCISE 77.—*Simple pendulum.*

Apparatus as in previous exercise, with the addition of a wood or cork bob.

Suspend by threads of the same length two pendulum bobs of the same size and shape, one composed of lead and the other of cork. Set these pendulums in vibration, with a small amplitude, by drawing the bobs aside by means of a flat piece of wood and releasing them simultaneously. Notice that the two pendulums have the same time of oscillation, so that this time does not depend on the mass of the pendulum bob.

Velocity.—The space passed over by a moving body in one second is, if the body moves at a constant speed, called the velocity of the body; and the velocity is said to be uniform. Thus a body which moves over 5 cm. in one second is said to have a velocity of 5 cm. per sec. The only case of a special name being given to a unit of velocity is the knot, which is a velocity of 1 nautical mile per hour.

In the case where the velocity is not uniform, but the body passes over different spaces in successive seconds, the velocity at any instant is the space the body would pass over if it continued to move for one second with the velocity it possesses at the given instant.

Acceleration.—When the velocity of a body is not uniform, the amount by which the velocity alters in a second is called the acceleration. Thus, if at one instant the velocity of a body is 10 cm. per second, while a second later the velocity is 15 cm. per second, then the body has an acceleration of 5 cm. per second per second, because the velocity has in one second increased by five centimetres per second. This is a case of a positive acceleration. If the velocity had in a second

decreased from 15 cm. per sec. to 10 cm. per sec., there would be a negative acceleration of 5 cm. per sec. per sec.

Falling Bodies.—When a body is allowed to fall freely, it is seen that it moves faster and faster as it falls; or, in other words, its motion is accelerated. It is, however, difficult to make experiments on bodies falling freely, because the rate at which they fall is so great. Hence we have to make use of some arrangement by which the motion is retarded, but still is of the same character as that of a body falling freely. From the results which we obtain in this way we shall be able to predict what will happen when a body falls freely. The first method which will be used for this purpose is to allow the body, in the form of a cylinder, to roll down an inclined plane.

EXERCISE 78.—*Motion on an inclined plane.*

Apparatus:—Smooth board, about 6 feet long, and 6 or 8 inches wide; a long wedge, about 3 inches thick at the wide end; metal cylinder used in Exercise 71; metronome; metre scale.

You are supplied with a long smooth board and a wedge. Place the wedge under one end of the board, so that this end is about one inch higher than the other. At about two inches from the higher end, draw a line across the board at right angles to the length. Place the metal cylinder used in Exercise 71 so as to touch the board along this line, holding it in place with a small block of wood resting on the inclined board. Set the metronome to tick seconds, and start the cylinder rolling by removing the block exactly on a tick. Then place a series of matches, or small pieces of wood, along the edge of the board, so that the cylinder passes the end of each of these exactly on a tick. Get the matches roughly in place first: then, as the cylinder rolls down, note whether at the moment of each tick it is exactly opposite each match; if not, move the match in the proper direction, and again allow the cylinder to roll down. After a little practice, if the matches are always laid at right angles to the length of the board, and as the cylinder passes you look along the match, you will soon find that you can adjust the positions with considerable accuracy. Measure the distances from the starting-point through which the cylinder has passed at the end of each second. It will be noticed that the space passed over in a second increases, so that the motion of the cylinder is

accelerated. Divide the distance passed through at the end of 1, 2, 3, 4, etc., seconds from the start by the squares of the corresponding times, that is, by 1, 4, 9, 16, etc., and enter the quotients, together with the time (t) and the space (s) passed over, in three columns, as in the following example :—

t.	s.	$\frac{s}{t^2}$
1 sec.	6·5 cm.	6·5
2 ,,	24·0 ,,	6·0
3 ,,	55·5 ,,	6·3
4 ,,	95·6 ,,	6·0
5 ,,	147·0 ,,	5·9

It will be found that the quotient $\frac{s}{t^2}$ is approximately constant, the greatest difference generally existing in the first value, for it is difficult to measure the small distance passed over in the first second with any accuracy. Thus we see that the space passed over increases as the square of the time, so that in 2 seconds the cylinder moves 4 times as far as in the first second, while in 3 seconds it moves 9 times as far as in the first, and so on.

Repeat the experiment with the plank inclined at greater angles —say, with the end raised 2 and 3 inches; in each case calculate the value of $\frac{s}{t^2}$ and enter your results in a table.

EXERCISE 79.—*Atwood's machine.*

Apparatus :—Atwood's machine ; metronome ; millimetre scale.

A simple form of Atwood's machine, which may be made at a small cost, is shown in Fig. 62. It consists of a strong upright pillar about 6 feet high, with a very light pulley, A, 6 inches in diameter at the top. The axle of this pulley consists of a fine steel knitting-needle, turning in two small pieces of glass tube cemented on the top of two upright blocks of wood. There are three sliding pieces, B, C, and D, which, by means of thumb-screws, can be fixed at any point on the upright. Of these, D carries a small projecting shelf, C carries a similar shelf, pierced, however, by a hole about 2 inches in diameter. The construction of B is a little more complicated, and is shown on a larger scale in Fig. 63. The platform F is hinged at G, being held in place by the spring-catch H. On pulling the string E, this catch is forced back and F is released, and by

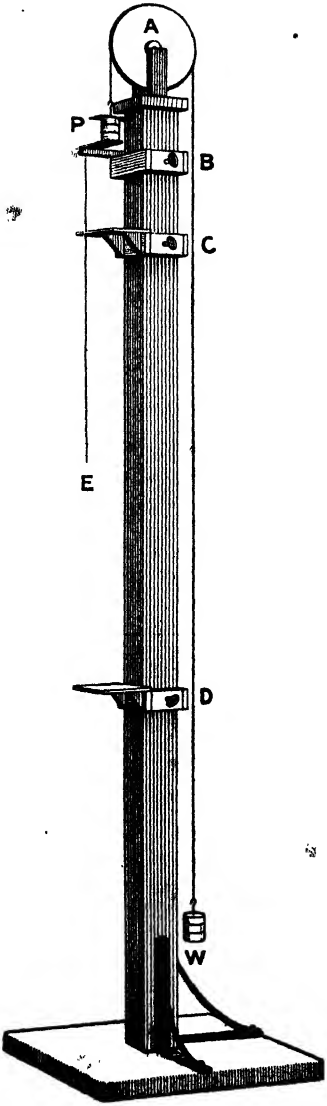

FIG. 62. ($\frac{1}{18}$.)

its weight and a piece of elastic, K, is rapidly pulled down.

A fine cord passes over the pulley, and has two weights, P and W, attached, one at each end.

If the weights P and W are exactly equal, they will stop wherever they are placed. Since, however, it is impossible to obtain a pulley without friction, add small discs of tinfoil to P till it is just on the point of moving W. When this adjustment has been made, P will remain at rest in any position; but if started downwards it will continue to move downwards, as far as it can go, with a constant velocity.

In order to set the masses P and W in motion, a small additional weight shown at M, Fig. 63, and called a rider, is employed. This weight is of such a length that it will not pass through the hole in the platform C.

Raise P, and set it on the top of the platform B. On the top of P lay the rider, so that the string passes through the middle of the hole. Start a metronome ticking seconds, and, allowing the string between the pulley and W to run lightly between the fingers, pull the string E exactly at a tick, and at the next tick stop P and W by clutching the pulley cord. Place the platform C on a level with the top of P. Then start again, but do not touch the pulley cord, and see whether the click

which is heard when the rider strikes the ring C occurs exactly at the second tick—that is, exactly after one second from the start. Move C till the tick and the click appear simultaneous. Now move the platform D till the weight P strikes it exactly on the third tick, *i.e.* two seconds from the start. The position of D can, as before, be roughly found by stopping the weights by clutching the pulley

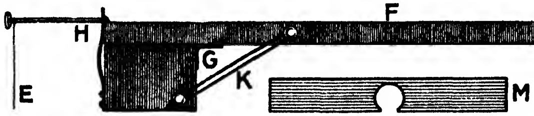

FIG. 63. ($\frac{1}{2}$.)

cord. Measure the distance between the top of the platforms C and D, and from this distance subtract the length of the weight P. You will thus obtain the space passed over by P and W in the first second after the removal of the rider which has set them in motion. In the same way, set the platform D so that the weight P strikes it exactly 2, 3, and 4 seconds after the removal of the rider.

Counting the time and distance moved over from the moment when the rider was removed, draw up a table as follows :—

Time $= t$.	Space $= s$.	Space passed over in one Second $=$ Velocity (v).
0 sec.	0·0 cm.	
1 ,,	20·5 ,,	20·5 cm.
2 ,,	41·2 ,,	20·7 ,,
3 ,,	63·0 ,,	21·8 ,,
4 ,,	84·0 ,,	21·0 ,,

It will be found that in each second P and W have passed over equal spaces, or the velocity has been constant, and that—

$$s = vt.$$

Hence, after the removal of the rider, the masses P and W move with uniform velocity till they are stopped by contact with D.

EXERCISE 80.—*Atwood's machine (continued).*

In the previous exercise the motion of the masses P and W has been studied after the force which set them in motion had ceased to act, namely, after the removal of the rider. We have now to examine the connection between the space passed over, and the time during which the moving force has been acting. As in the

previous exercise, adjust the ring C so that, starting at one tick, the rider may be removed exactly at the next tick. Measure the distance between the top of the platforms B and C, and add the length of the weight P. The sum will be the space passed through in the first second. Next lower C so that the click made when the rider strikes the ring may occur at the second tick after the start, and again measure the distance. Proceed in this manner for as many seconds as the height of the instrument will allow. It will be found that, as in Exercise 78, the space passed over in a second increases as P moves down, so that the motion is accelerated. Draw up a table similar to that on p. 103, giving the values of t, s and $\frac{s}{t^2}$. It will be found that the numbers in the last column are constant, showing that when a constant force (the weight of the rider $= r$) acts on a constant mass $(W + P + r)$, the space passed over is proportional to the square of the time from the start.

EXERCISE 81.—*Atwood's machine (continued).*

In the previous exercises the masses P and W, under the action of the force r, moved with increasing velocity; we now require to find the velocity at the end of each second. Adjust the position of C till the rider is removed exactly at the first tick after the start, then place the platform D so that P strikes it exactly at the next tick. Measure the distance between C and D, and subtract the length of P, thus obtaining the distance moved through in a second by P and W, when moving with the velocity which they possessed at the instant when the rider was removed; for the experiments made in Exercise 79 have shown that, after the removal of the rider, P and W continue to move with uniform velocity. Repeat the experiment, placing C so as to remove the rider after 2, 3, and 4 seconds, in each case adjusting the position of D so that P strikes it one second after the removal of the rider. In this way the velocity after 1, 2, 3 and 4 seconds will be obtained. Enter the results in a table, as below :—

Velocity at end of	Increase of Velocity in one Second = Acceleration.
0 sec. = 0 cm. per sec.	
1 ,, = 10 ,, ,,	10 cm. per sec. per sec.
2 ,, = 21 ,, ,,	11 ,, ,, ,,
3 ,, = 31 ,, ,,	10 ,, ,, ,,
4 ,, = 41 ,, ,,	10 ,, ,, ,,

From this table it will be seen that the increase of the velocity in each second is constant, or the acceleration is constant. Thus the mass $P + W + r$, when under the influence of the constant force r, moves with a constant acceleration.

EXERCISE 82.—*Atwood's machine (continued).*

In addition to the weights P and W used in the previous exercises, you are supplied with two others of greater mass. Repeat the experiments of the last exercise, using these fresh masses, determining the acceleration produced by the rider used in that exercise. Before making the experiment add tinfoil to P, as in Exercise 79, to allow for the friction of the pulley.

Determine the mass of P, W, and the rider used in this experiment, and also of those used in the previous exercise, thus getting in each case the mass moved.

Show, from your results in this and the previous exercise, that, if the moving force (the weight of the rider) is kept constant and the mass moved varied, the acceleration is inversely proportional to the mass, or that $a \times M =$ constant, where a is the acceleration, and M is the mass moved.

EXERCISE 83.—*Atwood's machine (continued).*

To test the effect of altering the moving force while keeping the mass moved constant, you are supplied with three riders of equal mass. Place two of these riders on P and one on W, and determine the acceleration; then place all three riders on P, and again determine the acceleration. The moving force is, in the second case, three times what it was in the first case. It will be found that the acceleration in the second case is also three times as great as it was in the first case. Thus, if the mass moved is constant, the acceleration is proportional to the moving force.

EXERCISE 84.—*Value of g.*

Let M be the total mass moved in Exercise 82 or 83, let r be the weight of the rider, and a the acceleration produced. If a is the acceleration produced when the mass M is moving under the influence of a force equal to the weight of r grms., what would be the acceleration produced if M were allowed to fall freely? In this case the moving force would be equal to the weight of M grms. Since the acceleration is proportional to the moving force, if g is the acceleration when the mass falls freely, then—

$$\frac{g}{a} = \frac{M}{r}$$

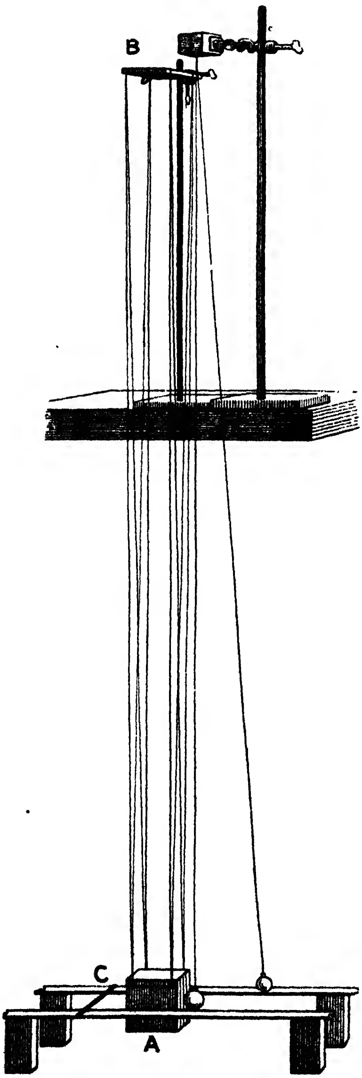

FIG. 64. ($\frac{1}{10}$)

because in one case the moving force and acceleration are r and a, while in the other case the moving force and acceleration are M and g, the mass moved being the same in both cases.

Calculate in this way from your results the value of the acceleration, g, when a body falls freely. Will the value of g be the same for all masses? Give reasons for your answer, remembering that the force with which the earth attracts a body is proportional to its mass.

EXERCISE 85. — *Momentum.*

Apparatus :—Cube of wood with 3-in. edge; two lead bullets, 100 grms. and 50 grms. in weight; two metre scales.

Drive four small nails into a cube of wood, and suspend it by strong thread, in the manner shown in Fig. 64. The suspending threads ought to be from 4 to 5 feet long, and are fixed at the top to a flat piece of wood, B, held in a retort-stand standing on the edge of the table. From a second retort stand suspend two lead bullets in the manner used in Exercise 75, so that when they are at rest they just touch the centre of the face of the block A. The block A should be suspended so

that the bullets will strike the end of the grain of the wood. Support two metre scales as in the figure, so that the cube will just swing between them without touching. Lay a piece of split straw, C against the face of the cube.

Having brought the cube to rest, and placed the 50-grm. bullet on one side, draw the other back through 10 cm., and let it go. It will strike the cube, which will be driven back, the distance through which it is driven being indicated by the straw C. Repeat the experiment several times, in each case starting with the cube at rest, and take the mean of the distances through which the cube has been driven.

Next repeat, using the 50-grm. bullet in the place of the 100-grm. one. It will be found that the cube is now driven back through a smaller distance than before. The velocity with which the bullet strikes the cube is the same as before, since the two bullets are suspended by strings of equal length. The blow struck the block is, however, less than before, so that the mass of the moving body evidently affects the intensity of the blow. Now gradually increase the distance through which the 50-grm. bullet is deflected, till the cube is driven through the same distance as it was when the 100-grm. bullet had been deflected through 10 cm.; suppose the distance is found to be x cm.

From the experiments made on the simple pendulum it follows that the time which elapses between the release of the bullet and the instant when it strikes the cube is the same whatever the amount of deflection, so long as this is not too great. From this it can be proved that the velocity with which the bullet strikes the cube is proportional to the distance through which the former has been displaced. Hence we may take the displacements as representing the velocity with which the bullet strikes the cube. Also, since the time of oscillation of a pendulum is independent of the mass of the bob (p. 101), it follows that the velocity with which the two bullets strike the cube is the same if the displacements are equal.

Therefore a mass of 100 grms., moving with a velocity represented by 10, strikes the cube a blow which produces the same effect as that struck by a mass of 50 grms. moving with a velocity represented by x.

Repeat the experiment, making the displacement of the 100-grm. bullet 15 and 20 cm. respectively, and in each case determine the distance through which the 50-grm. bullet must be displaced in order that the cube may be driven through an equal distance.

Enter your results in a table, as below, filling in the different columns.

100-GRM. BULLET.			50-GRM. BULLET.		
Mass.	Displacement = Velocity.	Mass × Velocity.	Mass.	Displacement = Velocity.	Mass × Velocity.

It will be found that the numbers obtained in the third and sixth columns are equal.

Momentum.—In the preceding exercise it has been found that, when two bodies of different mass, moving with different velocities, impinge on the same body, and communicate the same motion to this body, then the product obtained by multiplying the mass of each body by its velocity will be the same for the two bodies. This product of the mass of a moving body into its velocity is called its *momentum.* Thus, if a mass of M grammes is moving with a velocity of V centimetres per second, then its momentum will be MV units. The unit of momentum is the momentum of unit mass (1 grm.) moving with unit velocity (1 cm. per second).

EXERCISE 86.—*Ballistic pendulum.*

Apparatus:—Hick's ballistic balance.

For experiments on momentum the most convenient form of apparatus is that devised by Professor Hicks, and called the ballistic balance. Two light wooden platforms, A and B (Fig. 65), are suspended by a number of strong threads from some cross pieces, C, fixed to a wooden framework. The lengths of the threads and the position of the cross pieces, C, are so adjusted that when the two platforms are at rest they just touch, and when they are pulled to

the side they always remain horizontal. At the ends of A and B nearest each other two small blocks of wood are glued. Two sharp metal points project from one of these blocks, so that when the

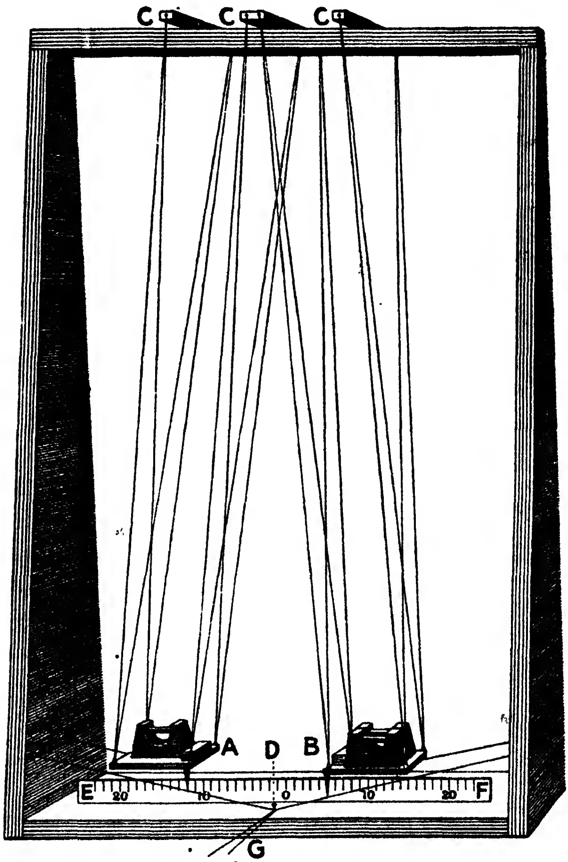

FIG. 65. (⅛.)

platforms come in contact these points imbed themselves in the corresponding block on the other platform, and thus, after impact, A and B adhere together. The platforms can be drawn aside by means of two fine threads which pass through two eyes at either

end, and are then brought one on either side of the pin D. By holding the two threads at C between the finger and thumb of the same hand, the two pendulums can be released at the same instant. The distances through which the pendulums have been pulled aside are read off on a scale, EF, two pointers fixed to the platforms serving for this purpose.

Put a pound weight in each of the platforms, and, drawing them aside through equal distances, let them go. It will be found that they meet at the zero of the scale, and are by the impact both brought immediately to rest. Thus the momenta are equal. Now displace one pendulum through 5 cm. and the other through 10 cm. It will be found that they meet as before at the centre of the scale, but are not brought to rest. The pendulum which was deflected through 10 cms. not only checks the motion of the other, but drives it back, continuing itself to move on in the same direction, but with diminished velocity.

Place two pound weights on the right-hand platform, and, displacing it each time 5 cms., adjust the displacement of the left-hand pendulum till when they meet they are both brought exactly to rest. As in the previous exercise, the velocities with which the platforms meet are proportional to the distances through which they have been displaced, so that these distances, as measured on the scales EF, can be taken as the velocities with which the bodies meet. Calculate the momenta, and enter in a table, as below :—

Pendulum A.			Pendulum B.		
Mass.	Distance displaced = Velocity.	Momentum at Time of Impact.	Mass.	Distance displaced = Velocity.	Momentum at Time of Impact.

Repeat the experiment, displacing B to different extents. It will always be found that, when the pendulums are both brought to rest by the impact, their momenta are equal.

EXERCISE 87.—*Ballistic pendulum.*

Apparatus:—Ballistic balance; lump of lead weighing about $1\frac{1}{2}$ lb.

The ballistic pendulum may be employed to measure the mass of a body. Place the body on the left-hand platform, and a 1-lb. weight on the right. Adjust the displacements till when the bodies collide they are both brought to rest. Let d_1 and d_2 be the displacements of the body and 1-lb. weight respectively, v_1 and v_2 the velocities at the moment of contact, and let M be the mass of the body. Then—

$$\frac{\text{momentum of body}}{\text{momentum of 1-lb. weight}} = \frac{Mv_1}{1 \times v_2} = \frac{Md_1}{1 \times d_2}$$

Therefore, since the momenta are equal—

$$Md_1 = 1 \times d_2$$

$$\text{or} \quad M = \frac{d_2}{d_1} \times 1 \text{ lb.}$$

Repeat, using different values of d_1 and d_2.

EXERCISE 88.—*Vibrations of a thin lath.*

Apparatus:—Vice; clock-spring 2 feet long; metronome.

Clamp one end of a piece of clock-spring in a vice, so that the free part projects about 60 cm. in a horizontal direction. Determine the time of oscillation of the spring for different amplitudes, by the method used in Exercise 75. It will be found that the time of oscillation is independent of the amplitude. Also measure the length of the free part of the spring.

Repeat the experiment for lengths of 50, 40, and 30 cm., calculating in each case the value of the quotient of the time of oscillation by the square of the length, and entering the results in a table similar to that used in Exercise 75. It will be found that, as in the case of the simple pendulum, the time of an oscillation will vary as the square of the length.

Gradually shorten the spring, and notice that the vibrations become faster and faster, till finally a deep musical note is obtained.

PART V.—SOUND.

EXERCISE 89.—*To prove that sounding bodies are in a state of vibration.*

Apparatus:—Steel knitting-needle; vice.

Take a steel knitting-needle or piece of clock-spring, and clamp it between the jaws of a vice so that about 6 inches project. Draw the end to one side and let go. A low deep note is given out, and you can see that the end of the needle is vibrating. Bring your finger-nail up to the end of the needle, and you will feel that it is in vibration, while the sound dies out as the vibrations of the needle are stopped by contact with your finger. Shorten the length of the needle projecting from the vice, and again set it in vibration. Is there any difference, and if so, what, in the character of the note you now obtain and that obtained with a greater length of needle? Since here, as in Exercise 88, you are dealing with the vibrations of a rod held at one end, to what conclusions do you arrive as to the connection between the rate of vibration of the knitting-needle and the pitch or highness of the note given out?

EXERCISE 90.—*The tuning-fork.*

Apparatus:—Two tuning-forks in unison, and a fork giving about four beats per second with either of these;[1] strip of glass; bristles and soft red wax.

Sound one of the tuning-forks supplied to you by sharply striking the end of one of the prongs against a block of wood. The blow ought to be a rap, not a steady blow. Note, by holding a piece of paper against the end, that the prongs are in vibration. Attach a piece of bristle about one centimetre long to one of the prongs of the tuning-fork by means of a *small* piece of soft red

[1] Such a fork can easily be prepared by slightly filing a fork which is in unison with the others.

wax, as at A, Fig. 66. Smoke a strip of glass about 6 inches long and 2 inches wide, by holding it over the flame of a paraffin lamp, from which the chimney has been removed. Lay the smoked glass, with the black side uppermost, on the table; then set the fork in vibration, and rapidly draw it across the glass, so that the point of the bristle just grazes the blackened surface. You will in this way obtain a wavy line, showing that the end of the fork has been in vibration. Now attach the bristle to the narrow edge of the prong, as shown at B, Fig. 66, and repeat the experiment. Make a drawing of the tuning-fork in your note-book, clearly showing the direction in which your experiments show that the prongs move when the fork is sounding.

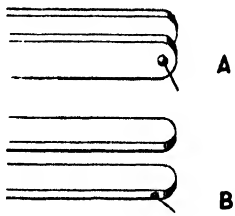

FIG. 66.

Take two forks of the same pitch and sound them together; notice that the sounds produced blend together and gradually die out. The forks are said to be in unison. Load the prongs of one of the forks by attaching a piece of red wax about the size of a pea to the end. Again sound the forks together. It will now be noticed that the intensity or loudness of the note produced seems to alternately increase and decrease. These alternations in the intensity are called *beats*, and are produced whenever two notes of nearly the same pitch are sounded simultaneously. Increase the weight added to the loaded fork, and notice that the beats become more frequent. Thus, by increasing the difference between the pitch, or number of vibrations per second of the forks, the number of beats per second has increased. It can be shown that the number of beats produced per second is equal to the difference between the numbers of vibrations per second of the two notes.

Find the number of beats produced per second by the two forks supplied to you, and thus obtain the difference in the number of vibrations per second made by the two forks. Also determine which fork makes the larger number of vibrations by weighting the prongs of one of the forks with a *small* piece of wax, and noticing whether the beats become more or less frequent. The experiments made on the effect of weighting one of the two forks which were in unison, ought to show you how to interpret your results in this experiment.

EXERCISE 91.—*To compare the frequency of two tuning-forks.*

Apparatus:—Stand and slide as shown in Fig. 67; small tuning-forks, A, C, G; 'cello bow; strip of glass.

Take two tuning-forks of different pitch, and attach a small length of thin bristle to the end of one prong of each. Clamp the handles of these forks firmly on the bevelled edge of the upright block A (Fig. 67) by means of the cross-bars and screws. The forks must be arranged so that the bristles are turned towards the upright slide, and are on the two inside prongs of the forks, being about half an inch apart. Smoke the surface of a strip of glass of such a size as to move easily in the upright slide. Place the smoked glass in the slide and prop it up with a piece of wood, B, to which a piece of cotton is attached, so that by pulling this cotton the prop will be removed and the glass allowed to fall. Loosen the screw by which the slide is clamped to the base, and move the slide forward till the ends of the bristles on both forks just touch the smoked surface, and clamp the slide in this position. Holding the end of the cotton attached to the prop in your left hand, or giving it to a second observer to hold, bow both of the forks simultaneously with a large violoncello bow. In bowing the forks, draw the bow fairly quickly and with a steady pressure over the edges of all four prongs. Go on bowing till both forks are sounding loudly. You can easily tell, from the fact that the notes are different, whether both forks are sounding. When this is so, allow the smoked glass to fall. *Before removing the glass*, move the slide away from the forks. If the experiment has been successfully performed, you will have two wavy lines traced side by side on the smoked surface. Do not be discouraged if you do not succeed in obtaining good traces at the first two or three attempts; you will find that a little practice will enable you to overcome all difficulties. After removing the smoked glass, mark opposite each of the traces the name of the fork; A, C, or G, as the case may

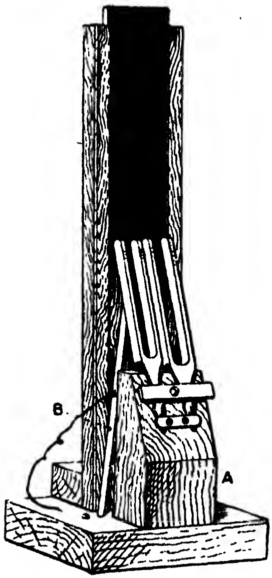

FIG. 67. (¼.)

be. Lay the smoked glass flat on the table, and place two metre scales, one on either side; on these rest a set square, bridging over the glass, and with a needle-point draw two fine lines right across the plate near the ends of the two traces and at right angles to these traces. Count the number of waves between the cross-lines in each of the traces. Then the number of oscillations per second, or the frequencies of the forks, are to one another as these numbers. Repeat the experiment, using another pair of forks, and calculate the ratio of the numbers of oscillations per second made by the G and A forks to the number made by the C fork.

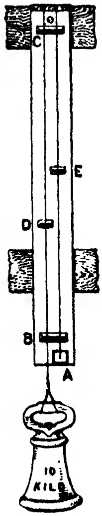

FIG. 68. ($\frac{1}{20}$.)

EXERCISE 92.—*To make a monochord.*

Take a board 3 ft. × 4 in. × $\frac{3}{4}$ in., and bevel off one end at an angle of about 45°, and on the bevelled edge fix two round-headed screws $1\frac{1}{2}$ inch apart. At the opposite end to these screws let in a block, A (Fig. 68), of some hard wood, such as mahogany or beech, $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in. × 1 in., making it a tight fit and glueing it in place, so that the centre of this block is on a line with the right-hand screw. Fix a wrest-pin into this block so that it is inclined at an angle of 45°, with its head leaning away from the screws. Cut two bridges 3 inches long and $1\frac{1}{4}$ inch high of the shape shown in Fig. 69; also cut two of the same height, but only $1\frac{1}{2}$ inch long. On the top of each of these bridges fasten a piece of thick brass wire, by bending the wire twice at right angles and driving the ends into the wood. Glue the two longer bridges on to the board at B and C, so that they are at equal distances from the ends and the brass wires on the top are exactly 30 inches apart. Glue a piece of thin cardboard on to the bottom of each of the small bridges, so that they are slightly higher than the other two. Take a piece of steel piano-wire (No. 22 S.W.G.) and twist a loop at one end, place it over one of the screws, pass the other end through the hole in the wrest-pin, and tighten the wire by turning the pin. Take a similar piece of wire and make loops at both ends, and pass one over the other screw. This wire will be stretched by hanging weights on the end.

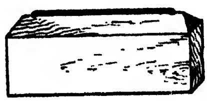

FIG. 69. ($\frac{1}{3}$.)

EXERCISE 93.—*The vibrations of a stretched string. (The relation between the pitch and the length.)*

Apparatus:—Monochord; tuning-forks C, G, and A; metre scale.

Pluck the keyed string of the monochord, and notice that you obtain a note. Show that the wire is vibrating by placing a small piece of folded paper over the wire.

Set one of the movable bridges at 10 inches from one end, so that the wire is divided into two portions, one exactly double the length of the other. Pluck each portion, and notice that the note given by the shorter is the octave of that given by the longer portion.

Place the two movable bridges under the keyed string, and adjust their position till, of the three portions into which they divide the wire, the two end ones are in unison with two of the given tuning-forks, say the C and A. Measure the length of these two portions with a millimetre scale, taking the distance between the points where the stretched wire touches the brass wires on the top of the bridges. Determine the ratio of these lengths by dividing one by the other, and compare with the ratio of the frequencies of the forks as obtained in Exercise 91. It will be found that the ratio of the lengths of wire in unison with the forks will be *inversely* as the frequencies. Thus, if the frequencies are as 3 to 4, the lengths will be as 4 to 3.

Make use of this method to determine the frequency of a fork of unknown pitch, being given that the C fork makes 528 vibrations per second. You must determine the lengths of the wire in unison with the fork of unknown pitch, and with the C fork. Then—

$$\frac{\text{frequency of given fork}}{528} = \frac{\text{length in unison with C fork}}{\text{length in unison with given fork}}$$

EXERCISE 94.—*The vibrations of a stretched string. (The relation between the pitch and the stretching force.)*

Apparatus:—Monochord; weights.

Fasten the monochord in a vertical position against the wall or table, and hang weights on the second wire so as to stretch it. Start with about 5 kilos, or 11 lbs. Adjust the position of one of the movable bridges till the upper portion of the wire is in unison with a tuning-fork, or with a certain length of the keyed string. Measure the length of the wire. Increase the stretching weight to

10 and then to 15 kilos, in each case determining the length of wire in unison with the fork or the fixed length of the keyed string. Arrange your results in a table, as in the example given below, and calculate the square of the length, and the quotient obtained by dividing the stretching force by the square of the length. It will be found that this quotient is constant, showing that the force required to stretch a string so as to give a note of any given frequency is proportional to the square of the length of the string. Thus, if the length of the string is doubled, the stretching force must be made four times as great, if the wire is to vibrate at the same rate as before.

Example—

Stretching Weight = F.	Length = l.	l^2	$\frac{F}{l^2}$
5 kilos	26·8 cm.	718	69·7
10 ,,	38·1 ,,	1452	69·0

EXERCISE 95.—*Vibrations of a stretched string. (The relation between the pitch and the diameter of the string.)*

Apparatus:—Monochord; weights; wires of different diameters; screw-gauge.

Determine, as in the previous exercise, the length of the wire stretched by a weight of 10 kilos in unison with a tuning-fork or a fixed length of the keyed string. Replace the wire by another of the same material, but of different diameter, and, using the same stretching weight, again determine the length in unison with the fork or keyed string. Measure the diameters of the two strings by means of a screw-gauge, and show that the lengths are inversely as the diameters, or, if d_1 and d_2 are the diameters and l_1 and l_2 the corresponding lengths, that $\frac{d_1}{d_2} = \frac{l_2}{l_1}$.

Vibrations of a Column of Air.—If the air contained within a tube closed at one end is set in vibration, then the note of lowest pitch which can be obtained, called the fundamental, is one for which the closed end of the tube A

(Fig. 70) is a node,[1] and the open end is a loop, and there are no loops or nodes between. The distance between two neighbouring nodes and loops is a quarter of the wave-length of the note, and therefore the length of a column of air, contained in a tube closed at one end, when sounding its fundamental, is a quarter of the wave-length of the note produced. If the air-column is sounding its first overtone,[2] there will be nodes at A′ and N and loops at L and B′, so that the length of the column of air is equal to three times a quarter wave-length or to three-quarters of a wave-length. If N is the number of vibrations per second corresponding to any note, and V and L are the velocity and wave-length of sound in the material in which the note is being propagated, then V = NL. Hence, if we can measure the wave-length in air of the note given out by a tuning-fork of known pitch, we can calculate the velocity of sound in air.

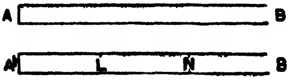

FIG. 70.

EXERCISE 96.—*Vibrations of a column of air.*[3]

Apparatus:—Resonance tube and tuning-fork.

Take a glass tube 60 cms. long and 3 cms. in diameter, and a tall glass jar, into which the tube will fit. This jar may consist of a length of about 50 cms. of glass tube, closed at one end with a cork and held in a retort clamp. Fill the jar with water, and, holding the tube vertical with one end dipping in the water, bring your vibrating tuning-fork over the other end. Raise or lower the tube in the water till the resonance is a maximum. Measure the length of tube above the surface of the water, thus obtaining the

[1] The nodes are the points where the alternate compressions and expansions of the air are a maximum. The loops are the points where the air is not compressed or expanded, but where the to-and-fro motion of the air-particles is a maximum.

[2] The overtones of a sounding body are those notes of higher pitch than the fundamental which may under certain circumstances be produced.

[3] It is impossible to perform this experiment satisfactorily in a room in which other acoustical experiments are being carried on. A quiet room is necessary.

length of the column of air which resounds to the fork. Continue raising the tube till a second position is obtained in which the resonance is a maximum. Again measure the length. In the first case the column of air enclosed in the tube was sounding its fundamental note in which there is only one node, and that at the surface of the water. In the second case there are two nodes, and the column of air is sounding its first overtone. Hence, if L is the wave-length in air of the note given out by the fork, the lengths of tube for which the resonance was a maximum are $\frac{1}{4}$ L and $\frac{3}{4}$ L respectively. Calculate from your observations the value of L; then, given that the fork makes —— vibrations in a second, calculate the velocity of sound in air.

Longitudinal Vibrations of a Rod.—In addition to the transverse vibrations already studied, a rod may be set in longitudinal vibration. Thus a rod held at the middle and then rubbed in the direction of its length may be set in longitudinal vibration, and give out a musical note. If the rod is sounding its fundamental, the middle point, at which the rod is held, is a node, while the two ends are loops. Thus the rod alternately shortens and lengthens, the two ends moving in towards or away from the middle at the same time. Since there is a loop at either end of the rod and a node between, the length of the rod is equal to two quarter wave-lengths, that is, half a wave-length of the note produced. It must be carefully noted that it is the wave-length of the sound travelling in the material of which the rod is composed, which is equal to twice the length of the rod, not the wave-length in air. If N is the frequency of the note produced, V the velocity of sound in the material of which the rod is composed, and L the length of the rod, then $V = 2NL$.

EXERCISE 97.—*Longitudinal vibrations of a rod.*

Apparatus:—Mahogany rods 5 and 6 feet long and $\frac{1}{2}$ inch in diameter; clamp for rod; monochord; tuning-fork.

Measure the length of the wooden rod supplied to you, and fix it in the clamp (Fig. 71) so that the length projecting on either side is the same, and fasten the clamp to the table either with screws or with an iron screw-clamp. Rub one end of the rod with a piece

of cloth or sheepskin on which a little powdered resin has been placed. The best note will be obtained if, starting near the middle of the rod, you draw the rubber with a slow and steady motion right to the end, and do not grasp the rod very tightly. Adjust the position of the movable bridge on the monochord till the note given by the wire is in unison with that given by the rod. Measure the length of the wire. Then find what length of the wire is in unison with the tuning-fork, and, given the pitch of the fork, calculate the pitch of the note given by the rod from the relation (Exercise 93)—

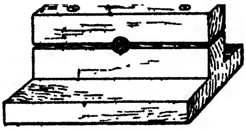

FIG. 71. ($\frac{1}{8}$.)

$$\frac{\text{frequency of rod}}{\text{frequency of fork}} = \frac{\text{length of wire in unison with fork}}{\text{length of wire in unison with rod}}.$$

Repeat the measurement, using a rod of the same material, but 5 feet long. Enter your results in a table as below:—

Length of Rod = L.	Frequency of Note = N.	L × N.

It will be found that the numbers in the last column are the same, showing that, as in the case of a stretched wire, the pitch or frequency of the notes are inversely as the lengths.

The wave-length being equal to twice the length of the rod, the velocity of sound *in the rod* is 2L × N. Calculate from your results the velocity of sound in the given rods. To do this you have only to multiply the numbers in the last column of the above table by two.

If any difficulty is found in tuning the wire to unison with the rod, take the rod out of the clamp, and, holding it with one hand with its middle pressed firmly against one of the fixed bridges of the monochord, rub it with the other hand. Then adjust the length of the wire till, on sounding the rod, the wire is set in violent vibration. In order to see when this occurs, place a small paper rider on the wire. When unison is reached, the rider will be violently thrown off each time the rod is sounded.

EXERCISE 98.—*To measure the velocity of sound in air by Kundt's method.*

Apparatus:—Glass tube, 1 inch bore and about 4 feet long; wooden rod and clamp as in previous exercise; lycopodium;[1] monochord.

Carefully dry the glass tube supplied to you by gently warming it over a Bunsen flame or before a fire, and then pushing through a plug of warm and dry cotton-wool. Hold this tube inclined at an angle of about 60°, and by means of a knife-blade pour lycopodium down one side of the tube. The best results will be obtained if the lycopodium lies in a thin continuous line all down the tube. Raise the tube, being careful not to disturb the lycopodium, and lay it on two V-shaped blocks of wood, A and B (Fig. 72). Attach

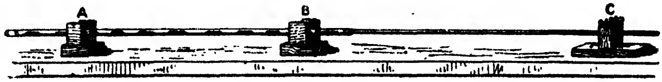

FIG. 72. ($\frac{1}{15}$.)

to one end of the wooden rod, either with glue or a small tack, a disc of cardboard of such a size that it will slip easily into the glass tube. Fix the rod by its middle point in the clamp C, and fix this latter firmly to the table. Then adjust the position and height of the glass tube so that the end of the wooden rod carrying the cardboard disc projects inside the tube, and so that the rod and tube are in line with one another. Now gently rotate the tube in the V's till the lycopodium is on the point of slipping out of the narrow strip in which it was first placed. Set the rod in vibration by rubbing with a resined cloth or leather. If the lycopodium shows no signs of gathering into heaps, close the far end of the glass tube with a cork and again set the rod in vibration. If there are still no signs of the formation of heaps, the glass tube must be moved so that the end of the rod projects about an inch further inside the tube, and another attempt made both with the tube open and closed. This shifting of the glass tube must be continued till the dust figures are most distinct. If it is found impossible to get the figures, either the tube is damp or too much lycopodium has been employed, and the only remedy is to thoroughly dry the tube or to use less lycopodium, as the case may be.

The places where the lycopodium is gathered together are the

[1] Grated corks may be used in place of lycopodium, and can be prepared by rubbing a cork on coarse sandpaper.

loops of the vibrations set up in the column of air enclosed in the tube by the to-and-fro movements of the end of the rod. Measure the distance between as many loops as possible, and, dividing by the number of *intervals*, get the distance between two adjacent loops. This distance will be half the wave-length in air of the note given by the rod; the length of the rod being half the wave-length of the same note in the wood of which the rod is composed. Let l be the wave-length in air, and L the wave-length in the wood of the note given by the rod, and let N be the number of vibrations per second or frequency of this note. Then—

$$\text{The velocity of sound in air} = Nl,$$

and

$$\text{the velocity of sound in the wood} = NL.$$

Obtain the value of N by comparing the pitch of the note given by the rod with a tuning-fork of known pitch by means of a monochord, as in the previous exercise. Then, knowing N and l, calculate the velocity of sound in air. If you have no fork of known pitch, you can only find the ratio of the velocity of sound in the rod and in air, this ratio being equal to $\frac{L}{l}$.

PART VI.—LIGHT.

EXERCISE 99.[1]—*The shadow photometer.*

Apparatus:—Rod fixed to small stand; white screen; candle and lamp; metre scale.

To compare the illuminating power of a lamp and a candle, take a block of wood about 12 inches by 8 inches, and stretch a sheet of clean white *blotting-paper* over one side, fastening it with drawing-pins. Stand this block upright to form a white screen, and about two inches in front place an upright rod of wood about 12 inches high and 1 inch in diameter. Set the lamp at a distance of about 3 feet from the screen, and move the candle about till the two shadows of the rod on the screen, one cast by the lamp and the other by the candle, are of equal darkness. It will be found that the adjustment can be best made if the lights are so placed that the two shadows on the screen touch, but do not overlap. Measure the distance of the candle-flame and lamp-flame from *the screen.*

Repeat the experiment with the lamp placed at 4 and 5 feet from the screen. Draw up a table as shown below, in which are entered the distances of the lamp and candle from the screen, the squares of these distances, and the ratio of the squares (*i.e.* the square of the distance of the lamp divided by the square of the distance of the candle).

Distance of Lamp from Screen = D.	D^2.	Distance of Candle from Screen = d.	d^2.	$\frac{D^2}{d^2}$

[1] This experiment must be performed in a darkened room.

It will be found that the numbers in the last column are approximately constant. Since the amount of light given out by the lamp and candle is the same at the different distances, the ratio of the illuminating power of the lamp to that of the candle is constant whatever the distance of the screen on which we compare these illuminating powers. But the ratio of the squares of the distances of the two sources of light from a screen which they illuminate equally (as shown by the equality in the darkness of the shadows cast by the rod) is also found to be constant. Hence the illuminating powers of the two sources of light (lamp and candle) are as the squares of their distances from the screen when the shadows are equally dark, so that the last column of the foregoing table represents the ratio of the illuminating power of the lamp to that of the candle.

Reflection of Light at a Plane Surface.—When a ray of light, called the incident ray, travelling in any medium, meets the polished surface of some different medium, a portion of the ray, called the reflected ray, is reflected, and the direction of this reflected ray obeys certain laws, called the laws of reflection. They are—

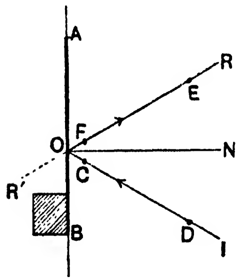

FIG. 73.

1. The incident ray, the reflected ray, and the normal[1] to the surface at the point of incidence;[2] all lie in a plane.

2. The angle between the incident ray and the normal, called the angle of incidence, is equal to the angle between the reflected ray and the normal, called the angle of reflection.

In Fig. 73, if AB represents a reflecting surface, IO a ray of light incident at O, OR the reflected ray, and ON the normal to the surface at O; then the first law states that the straight lines IO, ON, and OR all lie in a plane, while the second law states that the angle ION is equal to the angle NOR.

[1] The normal to a surface at any point is a line drawn through the point perpendicular to the surface.
[2] The point of incidence is the point where the incident ray meets the reflecting surface.

EXERCISE 100.—*Reflection at a plane surface.*

Apparatus:—Strip of thin mirror glass,[1] about 6 in. × 1 in., with a piece of wood fixed to the back so that it will stand upright; pins, paper, and pencil; protractor; scale.

Pin a sheet of paper on the top of your table or on a drawing-board, and on it draw a straight line, AB (Fig. 73). At any point O on this line draw a line ON at right angles to AB. Also draw a line OI, inclined at about 45° to AB. Place the strip of mirror supplied to you so that the edge of the reflecting surface lies along the line AB and the reflecting surface is vertical. At two points, C and D in the line IO, about 5 inches apart, stick two pins vertically into the paper. When you look into the mirror, the reflections of the two pins C and D will be seen. Move your eye about till, using one eye only, the reflections of the two pins appear in the same straight line, *i.e.* exactly one in front of the other. Keeping your eye in this position, stick a third pin, E, into the table so that it also may appear to be in the same straight line as the two reflections. Join the point where this third pin has been placed with O. Then this line gives the direction of the reflected ray when the incident ray is DCO. For the rays of light starting from D, and which, after reflection at O, enter the eye and produce the reflection of D, have passed along DC, since the reflections of D and C have appeared one in front of the other. These rays have also passed along OE, for the pin E also appeared exactly in front of the reflections of the other pins. Measure the angles ION, NOR by means of a protractor (see Exercise 62); it will be found that they are equal, showing that the angle of reflection, NOR, is equal to the angle of incidence, ION. Repeat the experiment, making the angle of incidence, ION, 30° and 60°.

[1] If glass silvered at the back is used, the refraction through the glass will in some cases cause a considerable error. Mirrors silvered on the front surface can be prepared by cutting ordinary thin ($\frac{1}{16}$ in.) looking-glass into strips 6 in. × 1 in., and placing these strips in a flat-bottomed vessel with the silvered side uppermost. Pour *hot* methylated spirit over the strips, when, after a few minutes, it will be found that the coating of varnish used to protect the silver will become quite soft, and may be removed by gentle friction with a pad of cotton-wool. The silver can then be polished with a piece of washleather and putty-powder or rouge. In order to protect the silver from the tarnishing action of the air, a thin and uniform coating of silico enamel may be put on. The silico enamel is used for coating plated goods and cycles, and can be obtained from most cycle outfitters. It is a good thing to place two needle points on the under surface of the block of wood fixed to the mirror, so that by pressing these points into the paper the mirror may be kept in place.

EXERCISE 101.—*Reflection at a plane surface.*

Apparatus as in previous exercise.

In order to show that the incident ray, the reflected ray, and the normal all lie in the same plane, having arranged the three pins, D, C, and E, as in the previous exercise, adjust C and D so that the tops of their heads may be at the same height above the surface of the paper. Then adjust the height of E and of another pin placed at F till, when the eye is placed at R, the *tops* of the heads of the four pins appear in a line. Measure the height of the top of E and of F above the surface of the paper. It will be found that the tops of E and F are at the same height as those of D and C. The incident ray from the top of D past the top of C, since D and C project equally above the paper, is parallel to the surface of the paper. The reflected ray which grazes the top of F and E is, for the same reason, also parallel to the surface of the paper. Since the mirror is at right angles to the surface of the paper, the normal at O must also lie in a plane parallel to the surface of the paper. But the three lines IO, ON, OR, all meet at a single point O, and each separately lies in a plane parallel to the surface of the paper. Hence they must all lie in the same plane. This fact may also be tested by resting some plane surface, such as a set-square, on the tops of the pins; it will be found to touch all the pins at the same time, and also to be parallel to the surface of the paper.

Images.—In the two previous exercises, when looking along the direction RO, the pin C was seen reflected in the mirror AB; and if we had not known that the mirror existed, we should have imagined that the pin was situated somewhere behind AB, along the line RO produced. If the mirror were removed, a pin could be placed at a certain point on RO produced, say at R′, so as to give the same appearance to an eye placed at R, as does the pin at C when the mirror is in place. Thus the pencil of rays of light which proceed from the pin C, and which after reflection reach the eye, and by means of which we see the pin, proceed after reflection just as if they came from R′. Whenever a pencil of rays, proceeding from a point such as C after reflection, either appear to diverge from or converge on some other point, this second point is called the *image* of the first. Thus the point R′ would be the image of C formed by reflection in the

mirror AB. If the rays of light after reflection actually pass through the image, this image is said to be *real;* if, as in the above case, the rays never actually pass through the image, but only travel after reflection as if they came from the image, the image is said to be *virtual.*

EXERCISE 102.—*Reflection at a plane surface.*

Apparatus as in previous exercise.

As in Exercise 100, draw a line, AB (Fig. 74), and a line, ON, perpendicular to AB. Place the mirror with the edge of the reflecting surface over AB, and at a point, P, on ON, about 6 inches from the mirror, place a pin. Also place pins at Q_1, Q_2, Q_3, etc., at intervals of about an inch. Then, as in the preceding exercises,

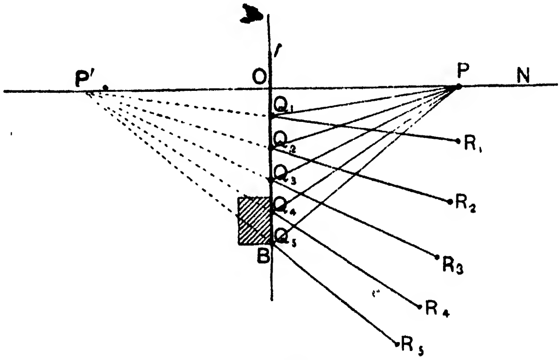

FIG. 74.

place pins at R_1, R_2, R_3, etc., to mark the directions of the reflected rays corresponding to the incident rays PQ_1, PQ_2, etc. Remove the mirror and join PQ_1, PQ_2, etc., and Q_1R_1, Q_2R_2, etc. These latter will be the reflected rays ; produce them backwards, and it will be found that they all meet at a point, P′. Thus the reflected rays Q_1R_1, Q_2R_2, etc., all proceed as if they came from the point P′, and P′ is the image of P formed by reflection in the mirror AB. Since the rays do not really pass through P′, the image is virtual. It will be found that P′ lies on PO produced, and that OP′ is equal to OP. Thus the image of P lies on the perpendicular drawn from P to the reflecting surface, and is as far behind the surface as P is in front of the surface. Repeat the experiment, placing P at various distances from the mirror.

Parallax.—If we have two pins, P and Q (Fig. 75), fixed upright on the table, and place our eye at B on the prolongation of the line joining the two pins, then one pin will hide the other, or, at any rate, appear immediately in front of it. If our eye, however, is at A, the pin Q will appear to the left of P; while if our eye is at C, Q will appear to the right of P. Thus, as we move our eye from A to C, the pin Q will appear to travel from left to right, passing behind P and appearing on the other side. It is important to remember that the more distant of the two pins appears to move in the same direction as that in which the eye is moved, while the nearer appears to move in the opposite direction. Thus if, on moving our eye, the relative position of two objects appears to change, then, of the two, that which appears to move in the same direction as our eye is the more distant. As an example of a case where this test may be applied, there are generally, at a panorama, a series of real objects placed between the picture and the place where the audience sits, and it is often very difficult to judge merely by looking where the real objects end and the picture begins. If, however, we move about, then all the real objects will appear to move with reference to one another, while the painted objects will always appear in the same relative positions. This method of testing the relative position of two objects, called the method of *parallax*, will be frequently made use of in the subsequent exercises.

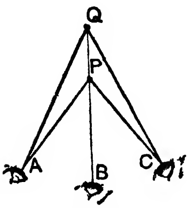

Fig. 75.

Exercise 103.—*To find the position of an image by the parallax method.*

Apparatus as in previous exercise.

Draw two lines, AB and OP (Fig. 76), at right angles, place the mirror with the reflecting surface over AB, and fix a pin into the paper at P. This pin should be of such a size that the head is about a quarter of an inch higher than the top of the mirror. Then looking in the direction PO, so that P and its image appear immediately one behind the other, place a pin somewhere behind

the mirror, as at Q, so that the top of this pin, seen over the top of the mirror, also appears in the same line as P and its image. Now move your eye to one side, say to D, and see whether the image of P, seen in the mirror, and the top of Q seen over the mirror, still appear in the same straight line one above the other. If Q has been placed behind the image of P′, as is shown in the figure, then Q will now appear to the left of the image P′; while if Q has been placed in front of P′, as at Q′, then it will now appear to the right of P′. Again looking along PO, move Q in the direction which the previous observation has shown to be necessary, and again see by the method of parallax, *i.e.* by moving the eye to D, if Q and P′ are at the same point. Move Q till the top of Q, seen over the mirror, appears, for *all* positions of your eye, to be a continuation of the lower part of the pin P, seen by reflection in the mirror. When this is so, Q must be at the position at which the image of P is formed, for if the mirror were removed, Q would appear, to an eye placed anywhere in front of AB, in exactly the same position as does the image of P when the mirror is present. Join the points P and Q, the line PQ will be found at right angles to AB. Also measure the distances PO, OQ; they will be found equal. Thus we find by this method, as by that used in the previous exercise, that the line joining an object and its image formed by reflection in a plane mirror is perpendicular to the mirror, and the image is as far behind the mirror as the object is in front.

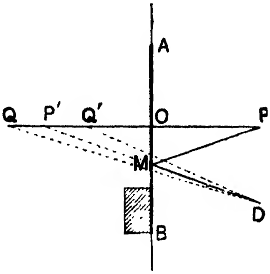

Fig. 76.

Cone of Rays which enter the Eye.—Owing to the size of the pupil of the eye more than one ray proceeding from a luminous point, either directly or after reflection, enters the eye to produce the impression on the retina which we call vision. Thus, in Fig. 77, the rays PQ_1R_1 and PQ_2R_2, after reflection at the mirror AB, enter the eye at R_1 and R_2, as do also all the rays

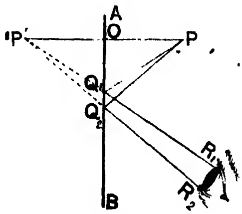

Fig. 77.

between these two, so that there is a cone of rays entering the eye, the apex of the cone being at P, and the base of the cone being equal in size to the pupil of the eye. If the rays R_2Q_2 and R_1Q_1 are produced back, they will intersect at P_1 the image of P, and it is always at the point of intersection of the rays which, coming from any luminous point, enter the eye, at which the eye *sees* the luminous point. Thus, the position in which we see any luminous point, and hence every object, depends solely on the direction of the rays just before they enter our eye.

EXERCISE 104.—*Lateral inversion of image in a plane mirror.*

Apparatus as in preceding exercises.

Cut a small arrow-head, PQ (Fig. 78), from cardboard, stick a pin through either end, and fix these pins upright on a sheet of paper. Place a mirror as at AB, and by the parallax method determine the position, P′Q′, of the images of the ends of PQ. Measure the size of PQ and of the image P′Q′. It will be found that the image and object are of the same size. It will also be noted that the position of the arrow in the image is laterally inverted. Thus, to an eye placed at E, the point of the arrow will appear turned to the left, while the point of the image will appear turned to the right.

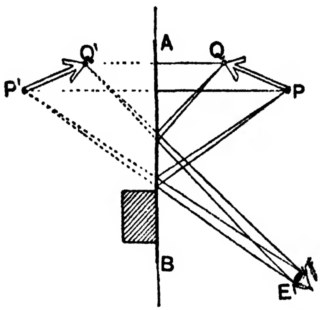

FIG. 78.

Draw on the paper the path of the small cones of rays proceeding from either end of the arrow which would enter an eye placed at E.

Images formed by two Plane Mirrors inclined at an Angle.—Let OA, OB (Fig. 79), be two plane mirrors, and let P be an object, say a pin, placed within the angle included between the mirrors. From P draw PR_1 perpendicular to the mirror OA, and make N_1R_1 equal to N_1P. Then R_1 will be the

image of P in the mirror OA. In the same way Q_1 will be the image of P in the mirror OB. In addition to these two

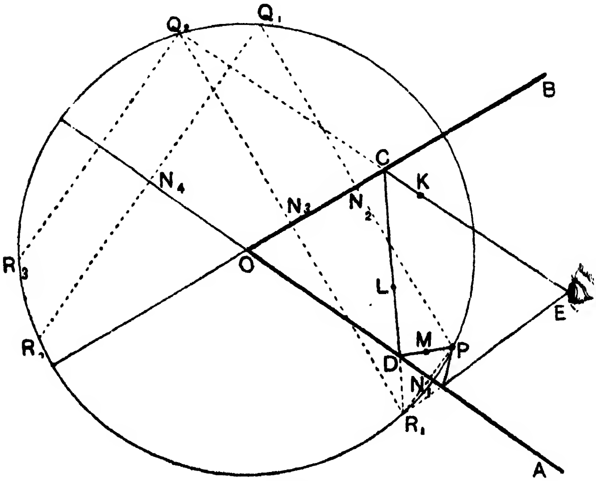

FIG. 79.

images, which are formed by rays which have been reflected once at one or other of the two mirrors, there will be other images formed by rays which have been reflected twice, once at each mirror. To find the position of such images, consider the rays which, starting from P, are reflected at the mirror AO: after reflection they travel as if they came from R_1; hence any ray such as PD, after reflection, will travel along DC as if it came from R_1. This ray, DC, will be reflected at the mirror OB. To find the direction in which it will be reflected, we may suppose the mirror OA removed, and the object P placed at R_1. From R_1 draw R_1Q_2 perpendicular to OB, and make N_3Q_2 equal to R_1N_3. Then Q_2 will be the image of R_1 formed in the mirror OB. Therefore the ray DC, after reflection at OB, will travel as if it came from Q_2, *i.e.* along CE. Thus an eye at E will see an image of P at Q_2, this image being formed by reflection first in AO, then in OB. In exactly the same way there will be an image at R_2 where Q_1R_2

is perpendicular to OA and N_4R_2 is equal to Q_1N_4. This image is formed by reflection, first in OB, then in OA. The two images, Q_2 and R_2, may in a similar way give other images formed by rays of light reflected three times. Thus Q_2 will give an image at R_3 formed in the mirror OA. R_2, however, cannot form an image in the mirror OB, since R_2 lies *behind* this mirror; neither can R_3 produce another image, for a similar reason. If a circle is drawn with centre O and radius OP, it will be found to pass through all the images.

EXERCISE 105.—*Images formed in two plane mirrors inclined at an angle.*

Apparatus as in Exercise 104, with the addition of a second mirror, a protractor, and a pair of compasses with pencil-point.

On a sheet of cartridge paper draw two lines, OA, OB, inclined at an angle of 70°. Place two mirrors with their silvered surfaces just over the lines OA, OB, and at a point such as P (Fig. 79), fix a pin upright in the paper. Then, by the method of parallax used in the previous exercise, place pins at the points where the five images formed are situated.

To trace out the path of one of the rays forming the image Q_2, fix a pin at E, and looking in the direction EQ_2, place a pin at K, so that the two pins E and K and the image Q_2 all appear exactly one behind the other. Next place pins at L and M, so that these pins also appear in line with the pins E K and the image Q_2 when you look along EK. Remove the mirrors, and place a small cross at the points where the pins are inserted, lettering these crosses as in the diagram. Join E, K, and produce this line to cut OB at C. Join C, L, and produce to meet OA at D. Then the line joining D and P will pass through M. Thus PDCE will represent the path of one of the rays forming the image Q_2.

With centre O and radius OP describe a circle: it will be found to pass through all the images. Also trace the course of one of the rays forming each of the images which would enter an eye placed at E.

In the same way, find by the parallax method the positions of the images formed in two mirrors inclined at 60° and 30°; also, for the first case, find the position of the images by geometry, by the method given on p. 133. Particularly note the positions of the images Q_3 and R_3, formed by rays reflected three times.

EXERCISE 106.—*Images formed in two parallel plane mirrors.*

Apparatus as in previous exercise.

Draw two parallel lines, AB and CD (Fig. 80), about 3 inches apart. Fix a pin, P, at about 1 inch from one of these lines, and

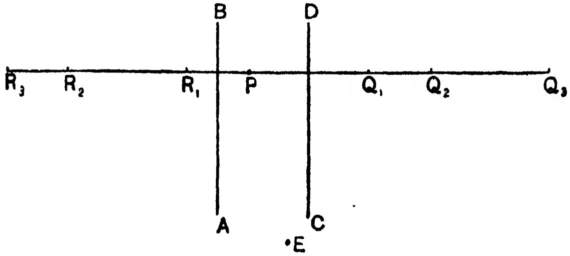

FIG. 80.

place two mirrors with their reflecting surfaces above AB and CD. Looking into either of the mirrors over the top of the other a number of images of P will be seen. By the parallax method fix pins to indicate the positions of the first three or four images formed in each of the mirrors. It will be found that all the images lie on a straight line, drawn through P, perpendicular to the mirrors. Measure the distances of the images from the lines AB and CD.

The images R_1 and Q_1 are formed by rays which have been once reflected. The image R_1 gives an image, Q_2, in CD, and therefore R_1 and Q_2 are at equal distances from the mirror CD. In the same way R_2 is an image of Q_1 formed in AB. Prove from your measurement that the images R_1, R_2, R_3, R_4, etc., each lie as far behind AB as P, Q_1, Q_2, Q_3, etc., lie in front of AB, so that R_1, R_2, R_3, etc., are the images of P, Q_1, Q_2, etc. Also prove that the images Q_1, Q_2, Q_3, etc., lie as far behind CD as P, R_1, R_2, etc., lie in front of CD, so that Q_1, Q_2, Q_3, etc., are the images of P, R_1, R_2, etc. Also draw the path of a ray forming the images R_2 and R_1 which would enter an eye placed at E (Fig. 80).

Reflection at Curved Surfaces.—In the previous pages the laws governing the reflection of light at a *plane*, or flat, surface have been examined; we have now to consider the reflection of light at a surface which is a portion of a sphere.

Such mirrors are divided into two classes: (1) those in which the reflecting surface is concave, *i.e.* the spherical surface is polished or silvered on the inside; and (2) those in which the reflecting surface is convex, *i.e.* the spherical surface is polished or silvered on the outside.

Reflection at a Concave Surface.—Let AOB (Fig. 81) represent the section of a concave mirror, so that the reflecting surface is turned to the right. A line, OX, drawn through the centre of the mirror, O, and the centre, C, of the sphere of which the mirror is a part, is called the axis of the mirror, and C is called the centre of curvature. Suppose a ray of light in the direction PD falls on the mirror at D; then, to find the path of the reflected ray, we have to draw the normal to the surface at D, and then make the angle of reflection equal to the angle of incidence, as in the case of reflection at a plane mirror. Since AB is a portion of a sphere, and C is the centre, CD is the normal at D. Hence, if we make the angle RDC equal to the angle PDC, DR will be the reflected ray. If the incident rays are parallel to the axis OC, then, after reflection, they all pass through a point, F, half-way between O and C. This point is called the principal focus of the mirror. Suppose a luminous point is placed at the centre of the mirror C, then all the rays proceeding from C will strike the mirror normally and be reflected back to C; for if CD is such a ray, then CD is the normal at D, and the angle of incidence is 0°, because the angle of incidence is the angle between the incident ray and the normal, and here CD is both the incident ray and the normal. Hence the reflected ray must also be inclined at 0° to CD—that is, the ray will be reflected back along DC. Thus, if an object is placed at C, an image will be produced by reflection alongside it. We can make use of this property to find the centre of curvature C; for if we

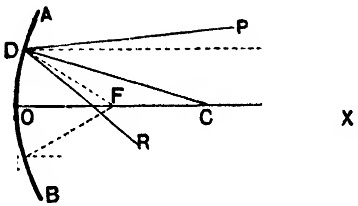

FIG. 81.

arrange the position of an object so that the image formed is alongside the object, then this object will be at the centre of curvature.

EXERCISE 107.[1]—*Concave mirror.*

Apparatus:—Concave mirror and stand; small screen; candle.

Place the concave mirror supplied to you in the holder on the table, and in front of it place a lighted candle. Arrange the height of the candle so that the flame is on a level with the centre of the mirror. On another stand fix a small screen, made by gumming a piece of white tracing paper or thin tissue paper about half an inch square on a wire frame, and adjust the height of this screen so that it is also on the same level as the centre of the mirror. Place the candle about 5 feet from the mirror, and move the screen about till you obtain a sharp image of the candle. Carefully note whether the image is erect or inverted, also whether it is larger or smaller than the object. Is the image formed real or virtual? Gradually bring the candle nearer and nearer to the mirror, for each position noting the size, etc., of the image. As you move the candle towards the mirror, in which direction does the image move?

Carefully determine the position where the image and object are alongside one another, and measure the distance of the image or object from the centre of the mirror. This distance will be equal to the radius of the sphere of which the mirror is a part, and is called the radius of curvature of the mirror. The direct light of the candle may be kept from the screen by holding a piece of cardboard between.

Next place the candle between the centre of curvature and the mirror, and again find the position of the image. A larger screen may with advantage be now used. Again note the position, size, etc., of the image.

Place the candle close to the surface of the mirror, being, however, careful not to place it so close as to run any chance of cracking the glass. Can you now obtain any real image on a screen? Looking at the mirror you will see an image of the candle. Is this image real or virtual? Give reasons for your answer.

Reflection at a Convex Surface.—In the case of a ray reflected at a convex surface, the construction for the reflected ray is similar to that employed with the concave surface. The

[1] This experiment must be performed in a darkened room.

centre of curvature and the principal focus are, however, behind the mirror, so that the centre of curvature cannot be found by placing a luminous point in such a position that the image and object lie alongside one another.

EXERCISE 108.[1]—*Convex mirror.*

Apparatus:—Convex mirror on stand; candle.

Place a candle in front of a convex mirror, and find for different positions of the candle whether the image is real or virtual, magnified or diminished, erect or inverted. Enter in your note-book a description of the experiments you make, and what conclusions you draw from them.

Refraction.—We have seen in the previous exercises how, when a ray of light, travelling in one medium (air), strikes a polished surface of another medium (silver), the direction in which the ray is travelling is altered and turned back into the first medium. We have now to study what happens to that portion of a ray of light which, striking a polished surface of some transparent material, instead of being reflected back into the first medium, travels on in the second medium. Suppose AB (Fig. 82) to be the surface of a block of glass, so that on the right of AB we have as the medium air, and on the left glass. Let PO be a light ray incident obliquely at O, then a portion of the light will be reflected along OR, according to the laws given on p. 126. The rest of the light will enter the glass, but will not continue to travel in the same direction as PO, but will be bent, or *refracted*, at the point O, where it enters the glass, so that the ray in the glass—the refracted ray, as it is called—will travel along OT. The refracted ray, however, lies in the same plane as the incident ray, the reflected ray and the normal at the point of incidence. If NON' is the

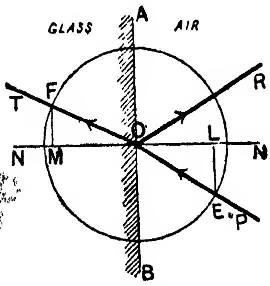

FIG. 82.

[1] This experiment must be performed in a darkened room.

normal to the surface separating the glass and air at the point of incidence O, then the angle T'ON' is called the angle of refraction. If with O as centre, a circle of any radius is described cutting the incident ray at E and the refracted ray at F, and EL and FM are drawn perpendicular to the normal NON', then the ratio of the lengths EL and FM is found to be a constant for any two given materials (air and glass in this case), whatever be the angle of incidence (PON). This ratio is called the *refractive index* from the first medium into the second.

EXERCISE 109.—*Refraction at a plane surface.*

Apparatus: — Drawing-board, paper, pins, compasses with pencil-point; steel millimetre scale; rectangular block of glass (*e.g.* letter weight).

Lay the rectangular block of glass supplied to you flat on a sheet of paper, and with a chisel-pointed pencil mark the outline of the block on the paper. Through a point O (Fig. 83), near the

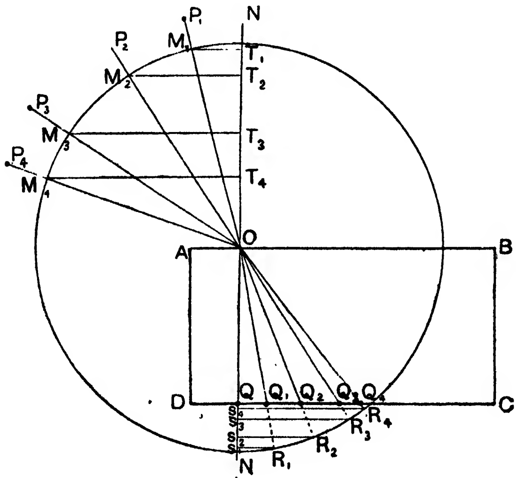

FIG. 83.

top left-hand corner, draw NON' at right angles to the side AB. Also from O draw four lines, OP_1, OP_2, OP_3, and OP_4, as in the

figure. With O as centre and a radius of about 4 inches, describe a circle. At O drive a pin upright into the paper, and at about 5 inches from O, along ON, fix another pin. Looking through the glass, place a pin, Q, against the edge, DC, of the glass, so that this pin and the other two pins appear exactly one behind the other. Then the direction of the incident ray is along NO, while the refracted ray is along OQ. It will be found that Q lies on the normal, so that when the incident ray is normal to the surface there is no refraction.

Next place a pin (P_1) at a point about 5 inches from O, along the line OP_1, and, as before, fix another pin, Q_1, against the edge, DC, so that the three pins, Q_1, O, and P_1, all appear one behind the other. Remove the glass and join OQ_1, and produce this line to cut the circle at R_1. Then P_1O is the incident ray, and OQ_1 is the corresponding refracted ray. From the point M_1 where OP_1 cuts the circle draw M_1T_1 perpendicular to NN′, and from R_1 draw R_1S_1, also perpendicular to NN′. Measure the lengths of M_1T_1 and of R_1S_1, and divide M_1T_1 by R_1S_1, entering your results in a table, as in the example given below. Proceed in the same way for the other incident rays, P_2O, P_3O, and P_4O.

Example :—

MT.	RS.	$\frac{MT}{RS}$
2·16 cm.	1·40 cm.	1·54
4·49 ,,	2·93 ,,	1·53
6·59 ,,	4·33 ,,	1·52
7·48 ,,	4·90 ,,	1·53

It will be found that the numbers in the last column of the table are the same, whatever the angle of incidence. These numbers are the refractive index of the glass, of which the block is composed.

EXERCISE 110.—*Refraction at two parallel plane surfaces.*

Apparatus as in previous exercise.

As in Exercise 109, place the block of glass flat on a sheet of paper, and trace the outline ABCD (Fig. 84). At a point, O, draw the normal NON′, and also a ray, PO, incident at about 45°. Fix pins upright at P and O. Replace the glass, and, looking through it, place a pin at Q, in contact with the face, CD, of the glass, so

that PO and Q appear one behind the other. Also place a pin at R, about 5 inches from Q, so that it also appears in line with the other three. Remove the glass and join OQ and QR. Then a ray incident along PO, when it enters the glass, is refracted towards the normal, along OQ. At Q, where the ray passes from glass to air, the ray is again refracted, but this time away from the normal M'QM, and proceeds in the direction QR. Produce the line PO to S. It will be found that PS is parallel to QR. Thus, a ray of light, after passing through such a slab of glass, the faces at which the ray enters and leaves the glass being parallel, travels in a direction parallel to the incident ray, but is shifted to one side. Measure the distance between PS and QR.

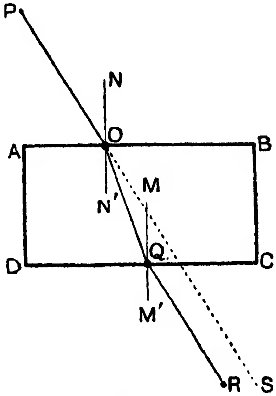

FIG. 84.

Repeat the experiment with rays for which the angle of incidence is 60°, 30°, and 0°, in each case measuring the amount of the lateral shift of the ray. Then turn the block of glass round, so that the ray enters at the face AD, and leaves at the face BC, and measure the lateral shift for rays incident at angles of 0°, 30°, and 45°. Draw up a table giving the angle of incidence, the distance between the faces of the block at which the ray enters and leaves, and the lateral shift. State to what conclusions, as to the connection between these three quantities, your results lead you, that is, answer the following questions: (1) How does the amount of the lateral shift alter as the angle of incidence increases? (2) How does the amount of the lateral shift alter as, keeping the angle of incidence the same, the thickness of the slab is increased? (3) Is there any angle of incidence, and, if so, what, for which the amount of the lateral shift is the same whatever the thickness of the block?

EXERCISE 111.—*Path of a ray of light through a prism.*

Apparatus:—Glass prism with an angle of about 30°; pins, paper, etc.

In the preceding exercise the path of a ray of light has been traced through a block of transparent material (glass), of which

the faces at which the ray entered and left the block were parallel. We have now to trace the path of the ray when these faces are not parallel, but are inclined at an angle. In order to investigate this question you are supplied with a right prism on a triangular base, made of glass, which in optics is generally called simply a prism. Lay this prism on a sheet of paper, with one of the triangular ends uppermost, and, holding the prism in place, trace the outline of the prism ABC (Fig. 85) on the paper with a chisel-pointed pencil. At a point, O, along one of the faces which enclose the acute (sharp) angle of the prism, fix a pin upright in the paper. Fix another pin at a point, P, about 5 inches from O. Then, looking through the prism, fix two other pins, R and S, so that they appear in line with the two pins P and O. Remove the prism, and join S and R, producing the line to cut the prism at Q. Join O and Q. Then the ray incident along OP is, on entering the prism, refracted along OQ. At Q this ray leaves the prism, and is again refracted, passing along QS. It will be found that QS is not parallel to PO, so that when a ray of light passes through a prism its course is deviated towards the thick end or base of the prism. Produce SQ to M, and PO to N, then the ray has been turned through the angle ONM. This angle is called the angle of *deviation.*

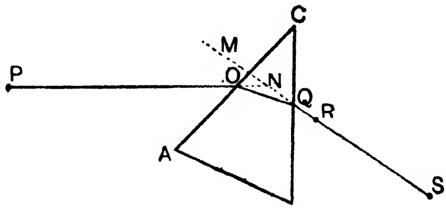

FIG. 85.

Keeping the pin P fixed, place the pin O at different points along AC, and in each case find the direction of the ray after leaving the prism. Produce all these rays back towards M, and it will be found that they meet at one point, P′. Thus we have the rays from P which are deviated by the prism proceeding, after they leave the prism, as if they came from P′. Hence P′ is the image of P (see p. 128). Prove that this is so by placing a pin at the image of P by the parallax method (see p. 130). That is, adjust the position of a pin at P′, so that the top of this pin, seen over the *top* of the prism, seems, when you move your eye from side to side, to be always a continuation of the lower part of the pin P seen *through* the prism.

EXERCISE 112.—*Dispersion by prism.*

Apparatus:—Prism with refracting angle of 60°; red and blue chalk pencil.

On a small piece of thin white cardboard, about 2 inches by 1 inch, rule two lines parallel to the length, one with a red pencil and the other with a blue. The lines should not be more than a millimetre wide, and should be close together, so that none of the white card shows up between them. On one side of the card let the red line be on the left of the blue, and on the other side let the red be on the right of the blue. Bend the card at the middle at right angles, so that it will stand with the lines vertical.

You are supplied with a prism having angles of 60°; place this prism upright on the table with the refracting angle turned towards the right, and at about 6 inches from the prism set up the card so that the face on which the red line is to the left is towards the prism. Then, looking through the prism, you will see the red and blue lines, the red being on the left, but notice that they seem broadened out. Now reverse the card so that the red line is now to the right. Again looking through the prism, you will see a red and blue line, but there will be this important difference, that while on the card the red line is to the right, when seen through the prism the red line appears to the left of the blue. Thus the red and blue rays of light coming from the two lines through the prism to the eye have crossed, and therefore the red and blue rays are deviated to different amounts by their passage through the prism. Write in your note-book an account of the above experiments, giving a sketch in each case of the arrangement, and state which of the two coloured rays is most deviated.

Dispersion of Light by a Prism.—In the preceding exercise it was found that, for a given angle of incidence, a ray of blue light was deviated by a prism through a greater angle than a ray of red light. Suppose that a pencil consisting of both red and blue rays were to fall on a prism, then the blue rays would be more deviated than the red, and the pencil would be split up into two, one of which would contain the red rays and one the blue, and the prism would have analyzed the pencil of rays of different colours into its constituent colours. Hence a prism may be used to test whether a pencil of light really consists of light of a single colour or of a mixture of light of different colours.

Exercise 113.—*Composite nature of white light.*

Apparatus as in previous exercise, with the addition of a bat's-wing burner and a piece of cardboard.

Take a piece of cardboard about 4 inches square, and in it cut a slit 1 inch long and a tenth of an inch wide. Fix this card in a retort clamp before a bat's-wing gas-burner, so that the slit is vertical. Then, standing at a distance of about 5 yards from the slit, look at it through the prism used in the last exercise, holding the prism with the refracting edge parallel to the slit (*i.e.* vertical). Instead of seeing a sharp white image of the slit, you will see a band of light showing the colours of the rainbow. Draw up a table of those colours you see that you can name, arranging them in order, starting with the colour which is most deviated.

In this experiment the rays of white light which, coming from the gas flame, strike the prism, are split up into a number of different coloured rays, so that what we call white light is really a mixture of light of all these different colours.

Spectrum and Spectroscope.—The band of colours into which white light is broken when it passes through a prism is called a spectrum. To study the spectrum use is

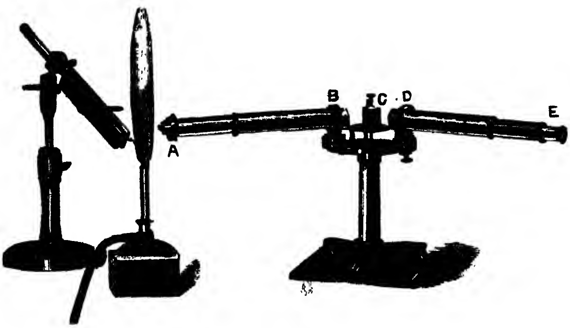

Fig. 86.

made of an instrument called a spectroscope, and shown in Fig. 86. It consists of a slit, A, through which the light enters the instrument. This slit is fixed at one end of a tube, AB, called the collimator, a lens being fixed at the other end, B.

The prism C is placed on a small table fixed to the instrument, and the spectrum is examined by means of a telescope, ED, which can be turned so that the light rays, after being deviated by the prism, may enter.

EXERCISE 114.—*Absorption of light by coloured bodies.*

Apparatus:—Spectroscope; bat's-wing burner; coloured glass; test-tube; copper; and nitric acid.

Place a bat's-wing burner in front of the slit of the spectroscope, so that the edge of the flame is turned towards the slit. Move the telescope till the spectrum is seen, then clamp it in this position. Place a piece of coloured glass between the flame and the slit, and it will be found that part of the spectrum is cut off. Use glass of various colours, ruby, green, blue, etc., and in each case make a note of the colours which are absent from the spectrum. These colours have been absorbed by the passage of the light through the coloured glass.

Place a deep ruby-red glass in front of the slit, only a red band will be seen; now place a piece of cobalt blue glass between the eyepiece and your eye, or in front of the red glass. No light now passes: the red glass absorbs all the rays except the red, while the blue glass absorbs the red rays; thus, no light can pass through them both.

Place a few copper turnings in a test-tube, and add a little nitric acid; close the end of the test-tube with a plug of cotton-wool. Brownish-coloured fumes will be given off and fill the tube. Place the tube in front of the slit of the spectroscope, and notice that there are a number of black bands across the spectrum. The light of the colour corresponding to each of these bands has been absorbed by the brown vapour.

EXERCISE 115.—*Bright lines of metals.*

Apparatus:—Spectroscope; Bunsen's burner; platinum wire; salts of various metals.

Replace the bat's-wing burner in the last exercise by a Bunsen burner. Take a piece of platinum wire a few inches long, and fuse one end into a piece of glass tube to form a handle. Dip this wire into a strong solution of common salt. Fix the glass handle in a retort clamp, so that the wire is in the flame of the Bunsen burner. Notice the bright yellow colour of the flame. Examine it through the spectroscope. It will be found that, in place of a long drawn-out spectrum, a sharp narrow yellow line alone is formed.

This line is the image of the slit, and since it is not drawn out we see that the light obtained when common salt (sodium chloride) is placed in a Bunsen flame consists of light of one colour only.

Carefully wash the wire, and then dip it into a solution of washing soda (sodium carbonate), the same yellow line will again be found. Thus we conclude that whatever it is that causes the yellow line occurs in common salt and in washing soda. It would, in the same way, be found that all compounds containing the metal sodium show this yellow line; and hence we conclude that, whenever this yellow line is found, sodium must form part of the body placed in the flame.

Repeat the experiment, using solutions of calcium chloride, strontium chloride, thallium chloride, lithium chloride, and magnesium chloride, in each case making a note of the number and colour of the bright lines observed. Be careful to well wash the wire before using a fresh salt.

EXERCISE 116.—*Dark lines in the solar spectrum.*

Apparatus:—Direct-vision spectroscope, lime-light.

Look at the sun through a direct-vision spectroscope, or arrange a piece of looking-glass so that sunlight is reflected in through the slit of the spectroscope used in the last exercise. A bright spectrum will be obtained, but, if the slit is made sufficiently narrow, it will be observed that this spectrum is crossed by a large number of fine dark lines.

Place a large Bunsen burner in front of the lime of an oxy-hydrogen burner, so that the flame of the Bunsen is between the lime and the slit of the spectroscope. While you watch the spectrum let another observer hold a small piece of metallic sodium, held in a small metal spoon, in the flame of the Bunsen. The flame will be coloured a very brilliant yellow, and the observer at the spectroscope will see a dark line appear crossing the spectrum in the yellow. Without disturbing anything, place a card between the lime-light and the Bunsen, so as to cut off the light from the former: a bright yellow line immediately appears at the place where the dark line previously existed. Thus, when a beam of white light is passed through a flame coloured yellow by sodium, the light of that colour which the sodium vapour itself gives out is absorbed, and thus a dark line is formed in the spectrum. Keeping this experiment in mind, to what conclusions do you come as to the cause of the dark lines observed when sunlight was examined through the spectroscope?

PART VII.—HEAT.

EXERCISE 117.—*Conductivity of solids for heat.*

Apparatus:—Small can for containing boiling water; rods of wood, glass, zinc, copper, and ivory or bone, about 4 inches long and $\frac{1}{8}$ inch in diameter.

Holding one end of a short copper rod in your fingers, dip the other end for about half an inch in boiling-hot water. Notice that the end in your fingers gradually gets hot, till it becomes too hot to hold. The end of the rod dipping in the hot water has been heated, and the heat has travelled, or been conducted, along the copper rod to the end between your fingers. Repeat, using the other rods in succession. It will be found that, in the case of rods made of some materials, such as wood, the end in your fingers does not get appreciably hotter. The copper rod is an example of a good conductor for heat, while wood is a bad conductor. Arrange as well as you can the rods supplied to you in order, placing the best conductor first, and so on.

EXERCISE 118.—*Comparison of conductivity of solids for heat.*

Apparatus:—Rods of copper, brass, and iron, 12 inches long, and 0·2 inch in diameter; piece of wood; beaker or tin vessel; paraffin wax.

Cover three rods, one each of copper, brass, and iron, with a thin coating of paraffin wax. To do this, warm the rods and rub them with a block of paraffin. Pass the ends of the rods through three holes, about $\frac{3}{4}$ inch apart, in a piece of wood, so that they project through for about 3 inches. Fill a tin vessel or a beaker, having a diameter of about 4 inches, with boiling water, and stand the piece of wood, through which the rods pass, on the top, so that the ends of the rods dip well into the hot water. The metal rods

will become heated, and the wax will melt. When the wax has melted as far as it will, which will take at least ten minutes, measure the distance from the top of the wood to the highest point on each rod at which the wax has melted. Then measure the distance from the top of the wood to the surface of the water, and add this length to those previously measured, in order to obtain the length along each rod, counted from the place where the heat was applied, through which the wax has melted. Repeat the experiment three or four times, and take the mean. The squares of the lengths obtained are proportional to the conductivities of the metals; hence calculate the ratio of the conductivity of copper to that of iron and of brass.

It will be found an assistance, when noting the extent to which the wax has been melted, to put the instrument in a good light, and watch the reflection of the light on the rods. For this reason the rods ought to be polished, though not lacquered.

EXERCISE 119.—*Conduction of heat in liquids.*

Apparatus:—Long, narrow test-tube; mercury.

Fill a long, narrow test-tube with cold water, and, holding the tube by the closed end, boil the water at the upper end over a Bunsen flame. It will be found that this can be done without the lower end becoming hot. Water is thus seen to be a bad conductor of heat. Replace the water by mercury, and again gently heat near the top. The lower end will be found to get hot, mercury being a good conductor of heat. All liquids, with the exception of mercury, are very bad conductors of heat.

EXERCISE 120.—*Method of filling an alcohol thermometer.*

Apparatus: — Thermometer tubing; alcohol, coloured with aniline magenta; foot blow-pipe.

Take a piece of thermometer tubing with a fairly wide bore (about $\frac{1}{32}$ inch) and at one end blow a strong bulb about $\frac{3}{4}$ inch in diameter (see p. 228). Connect the other end with a small glass funnel by means of a short length of indiarubber tube. Fix the tube upright in a retort-stand with the bulb at the bottom, and put some coloured alcohol in the funnel. Place a small tin, containing boiling water, so that the bulb is surrounded by the hot water. The air inside the bulb will expand, and some will escape in bubbles through the alcohol in the funnel. Remove the hot water, and allow the bulb to cool. Some of the alcohol will be sucked into

the bulb. Replace the hot water so as to make the alcohol contained in the bulb boil; and when it has all boiled away, again cool the bulb. The alcohol ought now to completely fill the bulb. If there is a small bubble of air left, the alcohol in the bulb must again be all boiled away.

When the bulb is quite full remove the funnel, and notice that, as the bulb cools, the alcohol contracts. Warm the bulb by holding it in your hand and notice the expansion, the alcohol rising in the tube.

The Thermometer.—The most commonly used instrument for measuring temperature is the thermometer. A form of thermometer suitable for the temperature measurements in these exercises is shown in Fig. 87. It consists of a bulb, B,

FIG. 87. ($\frac{1}{4}$.)

containing mercury and connected with a fine-bored stem, CA. The bulb is made cylindrical and of the same diameter as the stem, so that the bulb of the thermometer may, if necessary, be passed through a hole in a cork. It is advisable, however, whenever it is possible, not to try and push the bulb through a cork, but to thread the cork over the end A. The reason being that the bulb is made of very thin glass, in order that the heat may pass easily to the mercury, for it will be remembered that glass was found to be a bad conductor of heat. Hence never use the thermometer to stir the liquid in a vessel, as an accidental blow against the side would probably crack the bulb.

The scale of the thermometer is etched on the outside of the stem, and is such that, when the bulb of the thermometer is placed in melting ice, the end of the mercury column stands at the division marked 0. When the bulb and the stem are placed in the steam given off from water boiling when the barometric height is 76 centimetres, the end of the mercury column stands at the division marked 100. The space between these two marks is divided into a hundred equal

parts. The rise of temperature necessary to cause the end of the mercury column to pass through one of these divisions is called a degree centigrade, and is a hundredth of the difference in temperature between melting ice and water boiling under the conditions given above. Degrees of temperature are generally indicated in the same way as degrees of angle (see p. 79), with, in the case of degrees Centigrade, the letter C placed after—thus, a temperature of five and a half degrees Centigrade would be written $5^{\circ}\cdot5$ C.

Besides the Centigrade scale, there is another in common use in England, called the Fahrenheit scale. On this scale the interval between the temperature of melting ice and that of boiling water is divided into 180 parts. The temperature of melting ice, instead of being called 0°, is called 32°, so that the temperature of boiling water is, on the Fahrenheit scale, 212°. Degrees Fahrenheit are distinguished by having the letter F. placed after, so that the boiling-point of water is written 212° F.

EXERCISE 121.—*To test the correctness of the freezing-point (0° C.) of a thermometer.*

Apparatus:—Large funnel; ice; mercury thermometer, reading from -5° C. to $+105^{\circ}$ C.

Place the funnel supplied to you on the ring of a retort-stand, and attach a short piece of indiarubber tubing to the neck. Close this tubing with a pinchcock, and fill the funnel with finely pounded ice. The ice may be pounded by wrapping it in a piece of flannel, and hammering with a wooden mallet. Pour some distilled water over the ice. Then make a hole through the ice with a pencil, and insert the bulb of the thermometer in this hole, so that the 0° division is just level with the top of the ice. If necessary fix the thermometer in this position, by means of a thread fastened to the ring at the top of the thermometer and to the retort-stand. Allow the thermometer to stand in the ice till the reading becomes constant. It must be left in for at least ten minutes. Then carefully take the reading estimating to the nearest tenth of a degree, and being careful to note whether the thermometer reads higher or lower than 0°.

EXERCISE 122.—*To test the correctness of the boiling-point (100° C.) of a thermometer.*

Apparatus :—Hypsometer; thermometer; barometer.

In order to test the boiling-point of a thermometer, some means is required for surrounding the bulb and the stem up to the 100° mark with the steam given off by boiling water. For this purpose a hypsometer is employed. A form of hypsometer suitable for testing the thermometer supplied to you is shown in Fig. 88. It consists of an inner tube, AB, connected with a can, in which water can be boiled. This tube opens at its upper end inside a wider tube, FD. The tube, FD, is closed at the upper end by a cork, through which the thermometer to be tested projects, so that the bulb and the greater part of the stem are within the inner tube. The steam passes up the inner tube and down the outer, escaping, together with any condensed water, through the tube E.

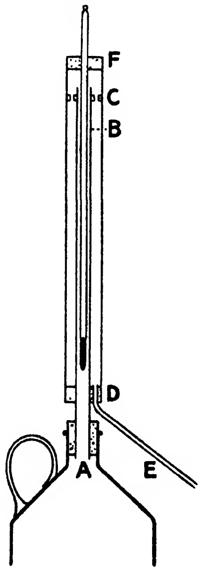

FIG. 88. (1/8.)

About half fill the can with water, and place it over a Bunsen burner to heat. Pass the thermometer through the cork F, so that the 100° mark projects about an eighth of an inch above the surface. When the water has been boiling from ten to fifteen minutes, read the thermometer and also the barometric height.

Since it is only when the barometric height is 76 cm. that the temperature of the steam given off from boiling water is exactly 100°, if the barometric height is not 76 cm. at the time of the experiment a correction will have to be applied. The amount of this correction can be easily calculated, for it has been found by experiment that for 1 cm. change in the barometric height the temperature of the steam changes by 0·36° C. If the barometric height is greater than 76 cm., the temperature of the steam will be greater than 100°; if the barometric height is less, the temperature will be less than 100°. The following example will show how the correction is applied:—

Barometric height = 76·8 cm.

Reading on thermometer when immersed in steam = 100°·6.

Since the temperature of the boiling water increases $0^\circ{\cdot}36$ for an increase of 1 cm. in the barometric height, the increase in temperature for 0·8 cm. will be—

$$0{\cdot}8 \times 0{\cdot}36 = 0^\circ{\cdot}29.$$

Hence the temperature of the steam at the time of the experiment was $100^\circ{\cdot}29$. The thermometer, however, read $100^\circ{\cdot}6$, and therefore it reads $100^\circ{\cdot}6 - 100^\circ{\cdot}3$, or $0^\circ{\cdot}3$ too high at the boiling-point.

EXERCISE 123.—*Effect of salt on the freezing-point of water.*

Apparatus:—Thermometer, reading to about -20° C.; test-tube and beaker; ice; salt.

Pound up some ice or use snow, and mix with it about a third of its bulk of powdered common salt. Plunge the bulb of a thermometer, graduated to about 20° below zero, in the mixture, and read the lowest temperature reached. It will be found that, by means of such a mixture of ice and salt, called a freezing mixture, a temperature of about -15° C. can be obtained.

Place some water in a test-tube, and plunge it in the mixture of ice and salt. Place the bulb of the thermometer in the water, and keep it continually moving up and down through about an inch. Notice that the temperature gradually falls, and, as soon as any ice forms, read the thermometer, and immediately remove it.

Melt the ice in the test-tube, and then add two or three pinches of common salt to the water, and again set it to cool. Note the temperature when ice begins to form.

Repeat the experiment, gradually increasing the quantity of salt added. To what conclusion do your results lead you as to the effect of dissolved salt on the freezing-point of water? Will it require a lower or higher temperature than 0° C. to freeze sea-water?

EXERCISE 124.—*Effect of salt on the boiling-point of water.*

Apparatus:—Wurtz flask (or ordinary flask with a long neck) of about 10 ounces capacity; thermometer.

Fit a cork to a flask of the shape shown in Fig. 89, and through this cork bore a hole,[1] so that the stem of the thermometer may fit fairly tightly. Fill the flask about half full of water, and heat over

[1] If an ordinary flask is used two holes must be bored in the cork, one for the thermometer, the other for a piece of bent glass tube.

a Bunsen burner, placing a piece of wire gauze between the flask and the flame, as shown in Fig. 98. When the water boils, notice that the thermometer steadily registers 100° C. when the bulb is in the steam, but when it is pushed down into the *water*, that the reading is often considerably higher than 100°, and does not remain steady. Add about 5 grms. of common salt to the water, and again boil. First place the bulb of the thermometer in the *liquid;* it will be found that the temperature is over 100° C. Then remove the thermometer and wipe the bulb, replacing it so that the bulb is in the *steam* given off by the boiling salt solution. Again read the temperature. State in your note-book what is the effect of adding some common salt on the boiling-point of water, and what is the effect on the temperature of the steam given off? From the results of these experiments, state what are the reasons for placing the thermometer in the steam given off by boiling water and not in the water itself, when testing the boiling-point of a thermometer.

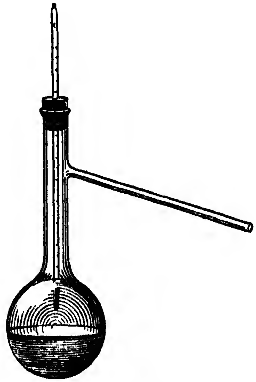

FIG. 89. (1/7.)

EXERCISE 125.—*Expansion of solids.*

Apparatus:—Zinc rod and iron gauge piece; can to contain boiling water.

You are supplied with a zinc rod, AB (Fig. 90), with accurately squared ends. When cold, this rod exactly fits inside the jaws of the plate of iron C. Remove AB, and heat it by plunging in boiling water. It will be found impossible to place AB between the jaws of C, as it is now too long. Hence, the rod has expanded owing to the heating. Next heat both AB and C in boiling water, and see if, now that both AB and C are again at the same temperature, it is possible to place AB between the jaws of C. To what conclusion as to the relative expansions of zinc and iron does this experiment lead you?

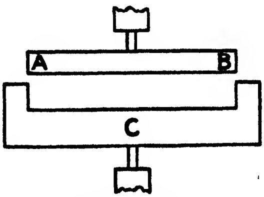

FIG. 90. (1/3.)

Coefficient of Expansion.—When a solid body is heated it expands in all directions, and if there are any two marks or points in the body exactly unit length apart, then the amount by which the distance between these points increases when the body is heated through 1° C. is called the *co-efficient of linear expansion* of the body.

Suppose the coefficient of linear expansion of a solid is a, and we have a cube of this solid, each edge being 1 cm. long; then, if this cube is heated through 1° C., each edge will expand and become $(1 + a)$ cm., and the volume will be $(1 + a)^3$ c.c. It can be shown by algebra that if, as is the case, a is a very small quantity, then $(1 + a)^3 = 1 + 3a$. Now, the volume of the body, when heated through 1° C., has increased from 1 c.c. to $(1 + 3a)$ c.c. Hence the increase of volume is $3a$ c.c. The increase in the volume of unit volume of a body when it is heated through 1° C. is called the *coefficient of cubical expansion* of the body. It therefore follows that the coefficient of cubical expansion of any body is three times the coefficient of linear expansion. In the case of liquids and gases, the coefficient of cubical expansion is the only one with which we have to deal.

EXERCISE 126.—*Expansion of liquids.*

Apparatus:—Piece of thermometer tube 10 inches long and $\frac{1}{32}$ inch bore, with a bulb about 1 inch in diameter at one end.

Fill the bulb supplied to you with alcohol (methylated spirit) by the method used in Exercise 120. Allow the bulb to cool before removing the funnel; and remove any small bubble that may be left, by shaking it up the tube. Then plunge the bulb, and as much of the tube as possible, into a vessel filled with water at about 60° C. Keep this water well stirred for about ten minutes, then measure the temperature with a thermometer, and remove all excess of liquid from the open end of the tube. If the liquid does not entirely fill the tube, measure the distance of the surface of the liquid from the end of the tube. Place the bulb in water at 50°, 40°, 30°, 20°, 10°, and in ice, in each case keeping the water well stirred for several minutes before taking a reading, and record the temperature and the distance of the end of the liquid column from the end of the tube.

Subtract the length obtained at each of the other temperatures from that obtained in melting ice, and thus get the distance along the tube the liquid has expanded for each of the temperatures. Since the bore of the tube is cylindrical, the lengths of the tube through which the end of the liquid column has passed are proportional to the increase of volume of the liquid, and these lengths may be taken as representing the increase in volume. Plot your results on curve paper, taking the temperatures as abscissæ, and the lengths along the tube counted from the 0° C. position as ordinates. Draw a smooth curve through the points, and read off the values for each whole 10° from 0 to 60°, and from these values see whether the expansion is the same for a rise of 10° at all temperatures between 0° and 60°.

Empty the tube of alcohol by placing the bulb in boiling water and allowing the alcohol to boil off. Then fill with water that has been recently boiled for at least ten minutes to remove the dissolved air. When filling the tube with water the bulb may be heated by being plunged in a boiling solution of common salt.

Starting at about 80°, take readings, as in the case of the alcohol, at every ten degrees down to 0° C., and plot the results on a curve. From this curve, and that for alcohol previously obtained, read off the expansion in each case from 0° to 60°. Since the volumes of water and alcohol taken are equal, the ratio of the expansions gives the ratio of the coefficients of cubical expansion of water and alcohol.

In the above experiments the glass bulb has expanded, and therefore increased in volume, so that the apparent expansion obtained is less than the true expansion of the liquid.

Suddenly plunge the bulb filled with *cold* water into *hot* water, and note the movement of the top of the liquid column. Write a description of what happens, and give an explanation.

Expansion of Water.—Most bodies when they are heated expand; water, however, between the temperatures of 0° C. and 4° C. contracts on heating. From this it follows that the density of water at 4° C. is greater than at any other temperature, and hence 4° C. is said to be the point of maximum density of water. Since the expansion which takes place between 4° and 0° is very minute, and is partly masked by contraction of the containing vessel, it is difficult to determine the point of maximum density of water by means of a bulb

and tube, such as was used in the last exercise. We may, however, make use of the fact that, if a body of water is at different temperatures at different parts, then those portions of the water which are of greatest density will sink to the bottom, while the lighter water will float on the top, to determine the point of maximum density.

A piece of apparatus (called Hope's apparatus) suitable for determining the point of maximum density of water on this principle is shown in section, in Fig. 91. It consists of a tall metal cylinder, AB, with a trough, C, at the centre, and two thermometers, D and E, one near each end. This metal cylinder is filled with water at a temperature of about 6° C, and then a freezing mixture, consisting of snow or pounded ice and crystallized calcium chloride, is placed in the trough C. By this means the water at the middle of the cylinder is cooled, and will either ascend or descend, according as in cooling it becomes lighter or denser. As a matter of fact it will become denser and sink, and this will be shown by the temperature registered by the lower thermometer, E, sinking rapidly, while the upper thermometer, D, will continue to indicate the same temperature. The temperature at the bottom will continue to fall till the thermometer E registers a temperature of 4° C, when it will remain stationary. The upper thermometer, D, which, up to now, has not indicated any fall of temperature, then begins to fall. This thermometer continues to fall till a temperature of 0° C. is reached. We thus see that the water at 4° C. is denser than water at any other temperature; for although the temperature of the upper

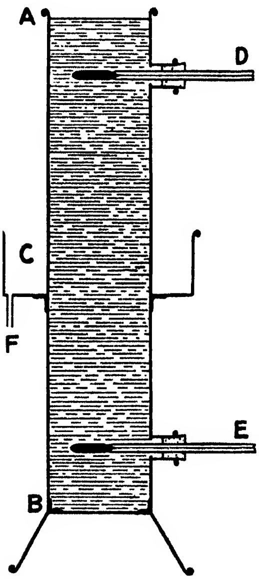

FIG. 91. (¼.)

water has sunk to 0°, yet it has not been able to displace the water at the bottom which is at 4°.

EXERCISE 127.—*Hope's experiment.*

Apparatus:—Hope's apparatus; crystallized calcium chloride; snow or ice.

Close the drain-tube F (Fig. 91) by means of a short length of rubber tubing and a clip, and fill the apparatus with water which has been cooled to 6° C. Then place a freezing mixture, obtained by mixing pounded ice or snow with half its weight of crystallized calcium chloride in the trough C, and read the two thermometers at intervals, entering the temperatures in two parallel columns. Continue reading till the thermometer D falls to 1° or 2° C.

Unless the water is cooled to 6° before being introduced into the apparatus it will be a long time (an hour or more) before the top thermometer begins to fall. This is due to the water at the top being less dense than water at 0°, and hence the cooling has to go on by conduction only, convection currents not being set up.

It is necessary that the whole instrument should be packed round with some nonconducting material, such as felt or cotton-wool, a pad being also placed over the top and underneath, in order to prevent the water being heated by the air of the room.

Enter in your note-book an account of the experiment, giving (1) the object of the experiment; (2) the method of carrying out the experiment; and (3) the conclusions to which your results lead.

Coefficient of Expansion of Gases.—The experiments made in the section on Boyle's law have shown that air is highly compressible—a property which it shares with all other gases. Hence, in the case of gases, we may either measure the amount by which the volume of a given mass of gas increases when heated, taking care to keep the pressure constant, or we may increase the pressure as the temperature rises, so that the volume of the gas remains unaltered, and then measure the increase of pressure. There are, therefore, two coefficients of expansion in the case of gases—one the coefficient of increase of pressure at constant volume, and the

other the coefficient of increase of volume at constant pressure. Liquids and solids are so very incompressible that the coefficient of increase of volume at constant pressure is the only one than can be observed.

Again, since gases expand so very considerably when heated, it is necessary to amplify the definition of the coefficient of cubical expansion in the case of these substances, and say that the coefficient of expansion is the ratio of the increase in volume or pressure, as the case may be, for a rise of 1° C. to the volume or pressure at 0° C.

Suppose the volume of a certain mass of gas at a pressure P_0 and at a temperature of 0° C. is V_0, and that the increase in volume when the gas is heated to 1° C., the pressure remaining constant is v; then the coefficient of increase of volume at constant pressure is $\frac{v}{V_0}$. If, when the gas is at 1°, the pressure is increased by an amount, p, so that the volume is again reduced to V_0, then, by Boyle's law (p. 60)—

$$(V_0 + v)P_0 = V_0 (P_0 + p)$$
$$\therefore V_0P_0 + vP_0 = V_0P_0 + pV_0$$
$$\therefore vP_0 = pV_0$$
$$\text{or, } \frac{v}{V_0} = \frac{p}{P_0}.$$

But $\frac{p}{P_0}$ is the coefficient of increase of pressure at constant volume. Hence we see that, for a gas which obeys Boyle's law, the two coefficients of expansion are equal.

It is found that all gases, as long as they are sufficiently removed from their liquefying-point, have the same coefficient of expansion, and that this coefficient is the same at all temperatures, so that they differ in these respects in a marked manner from both liquids and solids.

EXERCISE 128.—*Coefficient of increase of volume of air at constant pressure.*

Apparatus:—The arrangement shown in Fig. 92; metre scale.

The apparatus for this experiment consists of a narrow glass

tube, AB (Fig. 92), about a metre long, closed at A, but open to the air at B. This tube contains dry air, a thread of mercury, H, about three-quarters of an inch long, serving to enclose the air. The tube AB is, for the greater part of its length, surrounded by a wider tube, CD, the closed end being supported on a cork, G, which

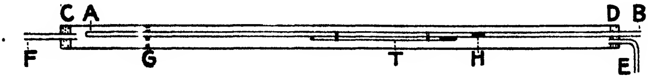

Fig. 92.

is pierced by a number of holes. The ends of the tube CD are closed by two corks, through one of which the end of the narrow tube and a piece of bent tube, E, pass; while a straight tube, F, passes through the other. A thermometer, T, is tied on the outside of the narrow tube.

Rest the tube CD in a horizontal position on two small V-shaped blocks of wood, connect F with the water supply and E with the sink, and pass a slow current of water through the space between the two tubes. Place a metre scale alongside the tube, with the zero opposite the end C of the outer tube, and after sharply tapping the tube to overcome any tendency the mercury index H may have to stick, read the position of that edge of this index nearer the closed end of the inner tube. While taking this reading be careful to hold your eye on a line drawn through the edge of H, and perpendicular to the scale. Also read the temperature on the thermometer T.

Disconnect F from the water supply, and connect it to a can in which steam can be generated. After the steam has been passing for a few minutes, and the thermometer shows that the temperature is constant, again tap the tube and read the position of the index, and also the temperature. Take the reading on the scale opposite the closed end of the tube A.

From your measurements calculate the coefficient of increase of volume of air at constant pressure, as in the following example :—

Temperature.	Reading for Index.	Reading for Closed End.	Volume.
9·5° C. 99·7°	65·8 cm. 84·8 ,,	8·2 cm. ,, ,,	57·6 76·6

$$\text{Rise in temperature} = 90{\cdot}2^\circ.$$
$$\text{Increase in volume} = 19{\cdot}0.$$
$$\therefore \text{ increase of volume for } 1^\circ = \frac{19{\cdot}0}{90{\cdot}2} = 0{\cdot}21.$$
$$\therefore \text{ volume at } 0^\circ = 57{\cdot}6 - 9{\cdot}5 \times 0{\cdot}21$$
$$= 57{\cdot}6 - 2{\cdot}0$$
$$= 55{\cdot}6.$$

The coefficient of increase of volume at constant pressure—

$$= \frac{\text{increase of volume for } 1^\circ \text{ C.}}{\text{volume at } 0^\circ \text{ C.}} = \frac{0{\cdot}21}{55{\cdot}6} = 0{\cdot}0038.$$

EXERCISE 129.—*Coefficient of increase of pressure of air at constant volume.*

Apparatus as in previous exercise, with the addition of a mercury manometer of the form shown in Fig. 93.

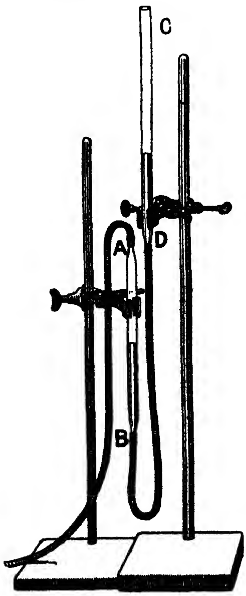

FIG. 93. ($\frac{1}{8}$.)

In addition to the apparatus used in the last exercise, you are supplied with an arrangement, shown in Fig. 93, by means of which the pressure acting on the air in the narrow tube can be increased, and this increase measured. It consists of two glass tubes about 8 inches long, and $\frac{3}{4}$ inch in diameter, the lower ends being drawn down, so that a piece of india-rubber tube about 18 inches long can be attached. The top end of one of the tubes, AB, is also drawn down, and can be connected by a piece of rubber tubing to the end B (Fig. 92) of the tube containing the air which is being experimented upon. Enough mercury to fill the rubber connecting tube and one of the glass tubes is placed in the instrument, so that by raising CD or lowering AB the pressure of the air in AB, and hence of the air in the heated tube, can be increased, the difference in level of the surface of the mercury in the two tubes giving the amount by which the pressure is increased.

Pass cold water through the jacket CD (Fig. 92), and when the temperature has become constant, read the thermometer and the position of the mercury index, as in the previous exercise. Then empty the jacket, and connect the open end of the tube with A (Fig. 93) by a piece of rubber tubing, binding a piece of thin copper wire round each junction. Pass steam through the jacket, and when the temperature becomes steady raise the tube CD (Fig. 93) till the mercury index comes back to its original position; then measure the difference of level between the mercury in the tubes AB and CD, and also read the barometric height. The pressure to which the air was subjected at the lower temperature is given by the barometric height, while the pressure at the higher temperature is equal to the barometric height together with the difference in level in the tubes AB and CD. Calculate the coefficient of increase of pressure at constant volume, entering your results as in the following example:—

Temperature.	Reading for Index	Barometric Height.	Manometer.	Total Pressure in cm. of Mercury.
9°·5 C.	65·8 cm.	78·0 cm.	0·0 cm.	78·0 cm.
99·7	,, ,,	,, ,,	25·5 ,,	103·5 ,,

Rise in temperature = 90°·2.

Increase in pressure = 25·5 cm. of mercury.

$$\therefore \text{ increase of pressure for } 1^\circ = \frac{25{\cdot}5}{90{\cdot}2} = 0{\cdot}28 \text{ cm.}$$

$$\therefore \text{ Pressure at } 0^\circ = 78{\cdot}0 - 9{\cdot}5 \times 0{\cdot}28$$
$$= 78{\cdot}0 - 2{\cdot}7$$
$$= 75{\cdot}3 \text{ cm.}$$

The coefficient of increase of pressure at constant volume—

$$= \frac{\text{increase of pressure for } 1^\circ \text{ C.}}{\text{pressure at } 0^\circ \text{ C.}} = \frac{0{\cdot}28}{75{\cdot}3} = 0{\cdot}0037.$$

Quantity of Heat.—In the preceding exercises the experiments performed have had to do with those properties of bodies which depend on their temperature. We have now to consider the measurement of quantity of heat.

The unit employed for measuring quantity of heat is the amount of heat necessary to raise one gramme of water from 0° C. to 1° C., or the amount of heat given out by one gramme

of water in cooling from 0° C. to 1° C. This unit of quantity of heat is called the *calorie*. We shall find that to within the accuracy with which all the observations in the following exercises can be made, it requires the same amount of heat to raise a gramme of water through 1° C. at any temperature between 0° and 100°. So that, as far as we are concerned, the calorie may be defined as the quantity of heat necessary to raise a gramme of water through 1° C.

EXERCISE 130.—*Thermal capacity of water at different temperatures.*

Apparatus: Beakers; thermometer; balance and weights.

Take two thin glass beakers of the same size, and each capable of holding about 300 c.c. Place these on opposite pans of a balance, and add shot to one pan till they are in equilibrium. Then fill one beaker nearly half full of cold water, and into the other beaker pour an equal weight of water at a temperature of about 40° C. Remove the two beakers, and stand them on a sheet of felt or cotton wool. Well stir the cold water, and read the temperature (t_1) with a thermometer. Then stir the hot water, read the temperature (t_2), and immediately pour all the hot water into the beaker containing the cold water. Stir the mixture well, and again read the temperature (t_3). Then $t_3 - t_1$ is the rise of temperature of the cold water, and $t_2 - t_3$ the fall of temperature of the hot water. The heat lost by the hot water has not only raised the temperature of the cold water through $t_3 - t_1$ degrees, but has also raised the temperature of the glass of the beaker through the same interval. To eliminate this effect repeat the experiment, using the same quantities of water at as nearly as possible the same temperatures, but pour the cold water into the beaker containing the hot water. In this case the temperature of the cold water is raised, not only by the loss of heat of the hot water, but also by the loss of heat of the glass of the beaker. The temperature of the mixture will, therefore, be just as much too high as it was before too low, so that by taking the mean of the two experiments the influence of the beaker will be eliminated. Take the mean of the two rises of temperature of the cold water ($t_3 - t_1$), and the mean of the two falls of temperature of the hot water ($t_2 - t_3$). It will be found, if the experiments have been carefully performed, that they are practically the same. Hence, as the mass of the hot and cold water was the same, just as much heat is given out when one gramme of water

cools from t_2 to t_3 as when 1 gramme of water is heated from t_1 to t_3, where the intervals $t_2 - t_3$ and $t_3 - t_1$ are equal.

Repeat the experiment, taking the initial temperature of the hot water (t_2) as 70° and 100°.

EXERCISE 131.—*Heat required to raise the temperature of alcohol.*

Apparatus as in previous exercise, with the addition of a supply of methylated spirit.

Repeat the experiment of the previous exercise, but instead of the *cold* water use cold methylated spirit, and mix this with an equal mass of hot *water.* It will be found that the alcohol is raised in temperature through a greater number of degrees than the temperature of the water falls, or, in other words, that $t_3 - t_1$ is greater than $t_2 - t_3$. Hence it follows that a gramme of alcohol requires less heat to raise it through 1° C. than does a gramme of water. From your results, neglecting the heat given out by the glass of the beaker, calculate the number of calories required to heat 1 grm. of alcohol through 1° C.

Specific Heat.—The experiment made in the preceding exercise has shown that a given mass of alcohol requires less heat to raise it through a given number of degrees of temperature than does an equal mass of water. Alcohol is, therefore, said to have a smaller *specific heat* than water.

The specific heat of a substance is the ratio of the quantity of heat required to raise a given mass of that substance through a given range of temperature to the quantity of heat required to raise an equal mass of water through the same range of temperature.

Since the calorie is the quantity of heat required to raise 1 grm. of water through 1° C., we may define the specific heat of a body as the number of calories required to raise the temperature of 1 grm. of the body through 1° C.

EXERCISE 132.—*Specific heat of copper.*

Apparatus:—Copper wire; heater; calorimeter; thermometer; balance and weights.

Take about 150 grms. of copper wire cut into lengths of about $1\frac{1}{2}$ inches, and tie them together with some cotton. Then carefully

weigh. Place the copper in a large test-tube, which hangs from the wooden lid of a tin vessel in which water is boiled; or hang the copper inside the steam heater shown in Fig. 94. The tube A is connected by means of a short length of rubber tubing to a can in which steam is generated, the steam and any water which condenses escaping through the tube B. The end of the cotton employed to tie the wire together should project outside, so that the copper may be easily withdrawn. Place a thermometer with its bulb alongside the copper, and lightly plug the open end of the inner tube with cotton wool. Boil the water in the can, and in the mean time carefully dry and weigh a small cylindrical vessel, about 3 inches high and $2\frac{1}{2}$ inches in diameter, made of very thin copper. Such a vessel is called a calorimeter. Fill the calorimeter a little more than half full of cold water, and again weigh. The difference in the two weights will give the weight of the water. When the temperature of the copper has become steady, it will be very near 100°, take the reading of the thermometer. Remove the thermometer, and, allowing it to cool a little first for fear of breakage, place it in the water in the calorimeter, well stir the water, and note the temperature. Then remove the copper from the heater, and, as quickly as possible, plunge it into the water contained in the calorimeter. Stir the water well, and note the highest temperature reached.

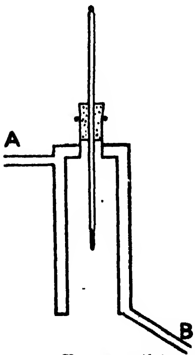

FIG. 94. ($\frac{1}{7}$.)

Now the heat given out by the copper wire in cooling has raised the temperature of the water and of the copper calorimeter. Let S be the specific heat of the copper and M its mass, w the mass of the calorimeter and W the mass of the water, t_1 the initial temperature of the water, t_2 the initial temperature of the copper wire, and t_3 the final temperature of the water and copper. The quantity of heat given out by 1 grm. of copper cooling through 1° is by definition (p. 163) S calories. Hence the heat given out by M grms. in cooling through 1° is M × S calories, and the heat given out in cooling through $t_2 - t_3$ degrees is $M \times S \times (t_2 - t_3)$ calories. The heat received by the water is $W(t_3 - t_1)$ calories, and the heat received by the copper calorimeter is $wS(t_3 - t_1)$ calories. But the heat given out by the copper wire is equal to the heat received by the water and the calorimeter. Therefore—

$$MS(t_2 - t_3) = W(t_3 - t_1) + wS(t_3 - t_1).$$

Since in this equation all the quantities, with the exception of S, are known, we can calculate S.

Determine in the same way the specific heat of lead. In this case use the value obtained in the previous experiment for the specific heat of copper to obtain the heat received by the calorimeter. Enter your results as in the following example :—

$$
\begin{aligned}
\text{Initial temperature of copper wire} &= 98^\circ\text{·}5\ \text{C.} \\
\text{Final}\quad ,,\quad ,,\quad ,, &= 22^\circ\text{·}1\ \text{C.} \\
\text{Fall of temperature} &= 76^\circ\text{·}4\ \text{C.} \\
\text{Initial temperature of water and calorimeter} &= 15^\circ\text{·}3\ \text{C.} \\
\text{Final}\quad ,,\quad ,,\quad ,,\quad ,, &= 22^\circ\text{·}1\ \text{C.} \\
\text{Rise of temperature} &= 6^\circ\ 8\ \text{C.} \\
\text{Mass of copper wire} &= 156\ \text{grms.} \\
\text{Mass of calorimeter} &= 52\text{·}5\quad ,, \\
\text{Mass of calorimeter + water} &= 215\quad ,, \\
\therefore \text{Mass of water} &= 162\text{·}5\quad ,, \\
\text{Heat lost by copper wire} &= MS(t_2 - t_3) \\
&= 156 \times S \times 76\text{·}4\ \text{calories.} \\
\text{Heat received by water} &= W(t_3 - t_1) \\
&= 162\text{·}5 \times 6\text{·}8\ \text{calories.} \\
\text{Heat received by calorimeter} &= wS(t_3 - t_1) \\
&= 52\text{·}5 \times S \times 6\text{·}8\ \text{calories.} \\
\text{But heat lost} &= \text{heat received.} \\
\therefore 11900^{1}S &= 1110 + 357\ S. \\
\therefore 11500S &= 1110 \\
S = \tfrac{1110}{11500} &= \text{·}096.
\end{aligned}
$$

EXERCISE 133.—*Change of State.*

Apparatus :—Calorimeter ; thermometer ; ice ; clock or watch.

Fill the calorimeter supplied you with pounded ice, and place it over some wire gauze on the ring of a retort-stand. Fix a thermometer so that the bulb is at about the middle of the ice. Turn a Bunsen burner down fairly low, and place it below the calorimeter for one minute. Then well stir the contents of the calorimeter, and read the temperature. Again heat for one minute and read the temperature. Proceed in this way till all the ice has melted. The flame may then be left continuously under the calorimeter, and the temperature read at the end of each minute till the water has boiled for three or four minutes.

Taking the time counted from the instant when you started

[1] The multiplications, etc., need only be carried out to the third significant figure, since the rise in temperature has only been measured to 1 in 68.

heating as abscissa, and the corresponding temperature as ordinate, plot your results on a curve. It will be found that this curve consists of three distinct parts : (1) a flat portion at the start, when there was ice present and when the temperature remained at 0° C. ; (2) an inclined portion while the temperature rose from 0° to 100° C. ; (3) another flat portion while the temperature remained constant at 100° and the water boiled away as steam.

Latent Heat.—In the experiment made in the preceding exercise heat was, during the whole time, being put into the calorimeter; but at two temperatures, namely, 0° and 100°, although this supply of heat was going on, the temperature did not rise. In each case, when the temperature remained stationary in this way, some change of state was going on. In the first case a solid (ice) was being converted into a liquid (water), while in the second case a liquid (water) was being converted into a gas (steam). This heat which is employed, not in raising the temperature of a body, but in changing it from a solid to a liquid, or from a liquid to a gas, is said to be latent. It is found that, when a gas condenses into a liquid or a liquid solidifies, the latent heat is liberated. The quantity of heat required to convert 1 grm. of ice at 0° C. into water also at 0° C., or, what amounts to the same thing, the quantity of heat given out when 1 grm. of water at 0° C. is converted into ice at 0° C, is called the latent heat of fusion of ice. In the same way, the quantity of heat required to convert 1 grm. of water at 100° C. into steam at the same temperature, or the quantity of heat given out by 1 grm. of steam at 100° when converted into water at 100°, is called the latent heat of vaporization of water or the latent heat of steam.

EXERCISE 134.—*Latent heat of fusion of ice.*

Apparatus as in Exercise 132, with the addition of some ice.

Weigh the calorimeter, and then fill it about two-thirds full of water at about 40° C. and again weigh. Remove the calorimeter, and wrap it round with cotton wool to prevent loss of heat. Stir well, and read the temperature. Then place in the water some small lumps of dry ice, till, when the ice is all melted, the temperature falls to about 10° C. The water must be kept well stirred during the melting of the ice. The ice may be dried by rapidly

pressing it between the folds of a duster or piece of blotting-paper. As soon as all the ice has melted, carefully read the temperature, then again weigh the calorimeter. The increase in weight gives the mass of ice melted.

Let L be the latent heat of fusion of ice, *i.e.* the number of calories required to melt 1 grm. of ice without changing the temperature, and M the mass of the ice melted. Then ML is the number of calories required to convert the M grammes of ice from ice at 0° into M grammes of water at 0°. If t_1 and t_2 are the initial and final temperatures of the water, then besides the ML calories necessary to melt the ice, Mt_2 calories are required to raise the water formed by the melting of the ice from 0° to t_2. The heat given out by the water and the calorimeter is—

$$W(t_1 - t_2) + wS(t_1 - t_2),$$

where W is the mass of the water, and w and S the mass and specific heat of the calorimeter. The value of S has been found in Exercise 132.

Since the heat gained is equal to the heat lost, we have :—

$$ML + Mt_2 = W(t_1 - t_2) + wS(t_1 - t_2),$$

from which L can be calculated.

Repeat the experiment two or three times, entering your results as in the following example :—

Weight of calorimeter = 52·5 grms.
Weight of calorimeter + water = 204·0 „
∴ Mass of water = 151·5 „
Weight of calorimeter + water + melted ice = 206·4 „
∴ mass of ice taken = 54·9 „
Initial temperature of water = 42°·3 C.
Final temperature of water = 10°·3 C.
Heat used in melting ice = ML = 54·9 × L calories.
Heat used in heating 54·9 grms. of water from 0° to 10°·3
= 54·9 × 10·3 = 565 calories.
Total gain of heat = 54·9 L + 565.
Heat lost by water = 151·5 × 32 = 4850 calories.
Heat lost by calorimeter = 52·5 × 0·096 × 32 = 161 calories.
Total loss of heat = 4850 + 161 = 5011 calories.

Since total gain of heat = total loss of heat

$$\therefore 54{\cdot}9\,L + 565 = 5011$$

$$\therefore L = \frac{5011 - 565}{54{\cdot}9} = \frac{4446}{54{\cdot}9} = 81 \text{ calories.}$$

EXERCISE 135.—*Latent heat of steam.*

Apparatus:—Calorimeter; thermometer; can for generation of steam and trap; balance and weights.

In order to determine the latent heat of steam, you are supplied with a tin flask in which water can be boiled. A glass tube bent at right angles is fitted by means of a cork into the neck of the flask. This tube is connected by about 10 inches of rubber tubing to the inlet tube A (Fig. 95) of a trap, which serves to catch any water which may be condensed in the tube. A *short and thin* glass tube, B, leads out from the trap. Weigh the calorimeter empty, and then about three-quarters full of cold water. Surround the calorimeter with cotton wool, and after stirring well, take the temperature. Then immediately dip the end of the steam-delivery tube, B, into the water and, keeping the water well stirred, allow the steam to pass till the temperature has risen to about 40° C. Remove the steam-delivery tube, and immediately read the temperature. Again weigh the calorimeter, the increase of weight, M, will give the mass of the condensed steam.

FIG. 95. (½.)

Let W be the mass of the cold water, and w and S the mass and specific heat of the calorimeter. Also let t_1 be the initial, and t_2 the final temperatures of the water. Then the heat given out by M grammes of steam at 100° in condensing to water at 100° is ML calories, where L is the latent heat of steam. This condensed steam in cooling from 100° to t_2 will give out $M(100 - t_2)$ calories. The heat gained by the water in the calorimeter is $W(t_2 - t_1)$ calories, and that gained by the calorimeter itself is $wS(t_2 - t_1)$ calories. Hence, since the heat lost is equal to the heat gained,—

$$ML + M(100 - t_2) = W(t_2 - t_1) + wS(t_2 - t_1),$$

and from this equation L can be calculated.

Repeat the experiment two or three times, entering your results as in the following example:—

Weight of calorimeter	=	52·5 grms.
Weight of calorimeter + water	=	224·3 „
∴ mass of water	=	171·8 „
Weight of calorimeter + water + condensed steam	=	179·1 „
∴ mass of steam used	=	7·3 „
Initial temperature of water	=	15·3° C.
Final temperature of water	=	39·5° C.
∴ change in temperature	=	24·2° C.

Heat given out by change of steam at 100° to water at 100°—

$$= 7{\cdot}3 \times L \text{ calories.}$$

Heat given out by 7·3 grms. of water at 100° cooling to 39°·5—

$$= 7{\cdot}3 \times 60{\cdot}5 = 442 \text{ calories.}$$

$$\text{Total loss of heat} = 7{\cdot}3\,L + 442.$$

$$\text{Heat gained by water} = 171{\cdot}8 \times 24{\cdot}2 = 4158 \text{ calories.}$$

$$\text{Heat gained by calorimeter} = 52{\cdot}5 \times 0{\cdot}096 \times 24{\cdot}2 = 122 \text{ calories.}$$

$$\text{Total heat gained} = 4280 \text{ calories.}$$

Hence, since heat lost = heat gained,

$$7{\cdot}3\,L + 442 = 4280$$

$$\therefore L = \frac{4280 - 442}{7{\cdot}3} = \frac{3838}{7{\cdot}3} = 526 \text{ calories.}$$

Vapour Tension and Boiling-point. The experiments made in Exercise 47 have shown that when a small quantity of a liquid such as water or ether is introduced into the vacuum of a barometer (the Torricellian vacuum as it is called), then the mercury column is depressed through a distance which is very much greater than could be due to the weight of the liquid. It was also found that so long as there was a little *liquid* floating on the top of the mercury column, then the depression due to the addition of more liquid was practically *nil*, being only due to the weight of the added liquid.

The depression of the mercury column indicates that the liquid gives off vapour which exerts a pressure, and the fact that the further addition of liquid does not increase the depression, shows that the pressure this vapour exerts is independent of the quantity of liquid present.

The distance through which the mercury column is depressed gives, in terms of a column of mercury, the pressure exerted by the vapour of the liquid or the VAPOUR PRESSURE.

The vapour pressure of any liquid is found to alter with temperature, and the temperature at which a liquid gives off bubbles of vapour, or boils, is that at which the vapour pressure is equal to the pressure of the atmosphere, or the pressure to which the liquid is subjected.

EXERCISE 136.—*Vapour tension of water at the boiling-point.*

Apparatus :—Barometer tube and steam jacket.

You are supplied with a barometer tube, which for most of its length is surrounded by a wider glass tube, AB (Fig. 96). The barometer tube is held in position by two corks, D and E, which, as shown in the cross-section K, are cut so as to allow the passage of steam. The tube F can be connected, by means of a length of rubber tubing, to a can in which steam is generated, the steam, after passing through AB, escaping at the bottom.

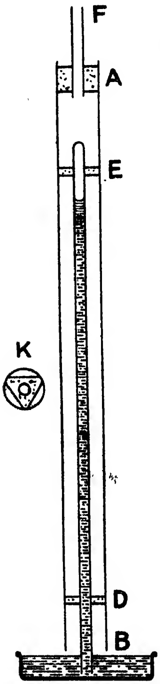

FIG. 96.

Without removing the barometer tube from inside AB, fill it with mercury, and invert over some mercury in a dish, fixing the tube in an upright position by means of a retort clamp, so that the open end of the wide tube is about a quarter of an inch *above* the surface of the mercury. The mercury dish had better be placed on the floor, and the can for generating steam on a table alongside. Pass a few drops of water up into the Torricellian vacuum (see p. 57), then pass steam into AB, and notice how the mercury column becomes depressed, so that, when the whole tube has been heated to 100° C., and steam issues from the bottom, the mercury stands at the same level inside and outside the barometer tube.

It is important that there should be a little water floating on the top of the mercury, even when the mercury is depressed to the utmost. Write a description of the experiment, carefully stating what it proves. Also explain why it is that the temperature at which water boils varies with the barometric pressure.

EXERCISE 137.—*Boiling-point of alcohol.*

Apparatus :—Wurtz flask ; thermometer.

Fit up a Wurtz flask in the manner described in Exercise 124, and fill it about a third full of alcohol (methylated spirit). Heat by means of a small Bunsen flame, and when vapour issues from the side tube, read the temperature shown by a thermometer, with its

bulb about an inch above the surface of the boiling liquid. Read and make a note of the height of the barometer, for, as in the case of water, the boiling-point varies with the pressure.

EXERCISE 138.—*Effect of change of pressure on the boiling-point of alcohol.*

Apparatus :—U-tube; tall beaker; thermometer; mercury; alcohol.

Pour mercury into the U-tube ABC (Fig. 97), running the mercury into the closed limb by tilting the tube, till the closed limb is just full, and the mercury will remain in the closed limb when the tube is held in the position shown in the figure. Pour some alcohol into the open limb CB, and, by slowly tilting the tube, allow a little of this alcohol to run into the closed limb.

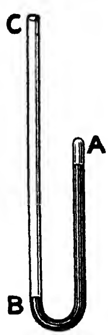

FIG. 97. (1/3.)

Fix the U-tube upright in a beaker of water, so that the *whole* of the closed limb is below the surface of the water. Slowly heat the water, keeping it well stirred all the time.

When the temperature of the water gets to within a degree or two of the boiling-point, as found in the last exercise, vapour will be formed in the closed tube. As soon as any vapour forms, stop heating the water. After well stirring the water note the temperature, and measure the difference in level of the mercury in the closed and open tube. Increase the temperature of the water by about two degrees, and again note the temperature and the difference in level of the mercury in the two limbs. If it is possible, without driving the mercury round the bend, again increase the temperature by two degrees.

The vapour pressure of the alcohol at each of the temperatures is equal to the barometric height + or − the difference in level of the mercury in the two tubes. Hence calculate the change, near the boiling-point, in the vapour pressure of alcohol, for a rise of temperature of 1° C., as in the following example :—

Temperature.	Barometric Height.	Difference in Level of Mercury in U-tube.	Vapour Pressure in cm. of Mercury.
76·5° C.	76·2 cm.	6·1 cm.	70·1
78·6° C.	,, ,,	0·0 ,,	76·2
80·1° C.	,, ,,	4·8 ,,	81·0

(1) Change in temperature = $2{\cdot}1°$; change in vapour pressure = $6{\cdot}1$.
(2) " " = $1{\cdot}5°$; " " = $4{\cdot}8$.

$$\therefore \text{ (1) Change in vapour pressure for } 1° = \frac{6{\cdot}1}{2{\cdot}1} = 2{\cdot}9 \text{ cm.}$$

$$\text{(2) " " " } = \frac{4{\cdot}8}{1{\cdot}5} = 3{\cdot}2 \text{ cm.}$$

$$\text{Mean " " " } = 3{\cdot}0 \text{ cm.}$$

From your results calculate, in a way similar to that employed on p. 151, what would be the boiling-point of the alcohol used in Exercise 137, at the normal barometric pressure of 76·0 cm.

Distillation.—It has been found in the preceding exercise that alcohol boils at a lower temperature than water. Now, at the temperature at which alcohol boils, its vapour pressure is equal to the barometric pressure, while the vapour pressure of water at this temperature is much less. Hence, if a mixture of water and alcohol is heated to its boiling-point, the vapour pressure of the alcohol, which measures the tendency of the alcohol to become vapour, will be much greater than the vapour pressure of the water. Thus, when such a mixture boils, the vapour which is at first formed will contain a very large proportion of alcohol. As the proportion of alcohol in the boiling liquid decreases, the proportion of alcohol in the vapour will also decrease, till, finally, the residue is water almost free from alcohol. During this process the boiling-point of the mixture will gradually rise from a temperature somewhat near that at which pure alcohol boils to that at which pure water boils.

The above property may be made use of to separate two liquids, such as alcohol and water, which have different boiling-points. For this purpose the mixture is placed in a flask and boiled, the vapour given off being condensed by being passed through a tube which is kept cool. Such a process is called *distillation*. The first half of the liquid which is distilled over contains a larger proportion of the liquid with the lower boiling-point, while the residue left in the flask contains a larger proportion of the liquid with the higher boiling-point.

EXERCISE 139.—*Distillation.*

Apparatus:—Wurtz flask; condenser; thermometer; Hare's apparatus.

Take a glass tube 12 inches long and $1\frac{1}{4}$ inches in diameter, and fit a cork at either end. Through the centre of these corks bore a hole, so that a length of glass tube, DC (Fig. 98), about $\frac{1}{4}$ inch in

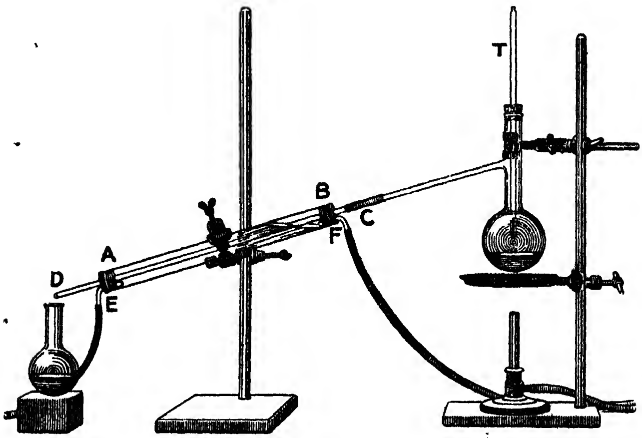

FIG. 98. ($\frac{1}{10}$.)

diameter, can pass tightly through. Also bore a second hole in each of the corks, to fit two small bent pieces of glass tube, E and F. Connect the central tube DC with the side tube of a Wurtz flask, supporting the apparatus in the manner shown in the figure. Connect E with the water-supply, and lead a tube from F to the sink. By passing cold water through AB, the vapour which distils over from the flask is condensed into liquid, and may be collected in a flask at D.

Make a mixture containing about equal volumes of water and methylated spirit, and determine the density of the mixture by means of Hare's apparatus (Exercise 35).

About half fill the Wurtz flask with the mixture, and, keeping a current of cold water flowing through the condenser AB, heat the flask with a Bunsen flame. Note the temperature at the end of each minute as the distillation proceeds, stopping the process when about half the liquid has distilled over.

Measure the density of the distillate, and also of the residue, in the flask. Then from the following table, which gives the number of cubic centimetres of alcohol in 100 c.c. of a mixture of water and alcohol of different densities, calculate the number of cubic centimetres of alcohol in 100 c.c. of (1) the original mixture; (2) the distillate; (3) the residue in the flask.

Density	·79	·82	·85	·87	·90	·92	·94	·96	·97	·98	1·00
Cubic cm. of alcohol in 100 c.c.	100	90	80	70	60	50	40	30	20	10	0

Also distil a solution of common salt, and notice that the distillate is free from salt, so that distillation is a method of preparing drinkable water from sea-water.

PART VIII.—MAGNETISM.

EXERCISE 140.—*Magnets.*

Apparatus:—Bar magnet.

The bar magnet with which you are supplied is a bar of hard steel. It differs from an unmagnetized bar of steel in several important particulars. In order to study these properties which distinguish a magnetized bar, perform the following experiments, in every case recording in your note-book, and in your own words, the method in which you have performed the experiment, and the results you obtain; also give any conclusions to which these results may lead.

1. Show that a magnet will attract pieces of iron or steel, such as nails or needles. Try whether the magnet will attract other bodies, such as wood, paper, glass, brass (a pin).

2. Try whether both ends, and also whether the middle of the bar, will attract pieces of iron, such as tin-tacks.

3. Plunge a magnet into iron filings, or scatter iron filings over a magnet. Note the curious tufts formed. Make a drawing of the magnet and tufts.

4. Place a needle on the top of a sheet of cardboard, and move one end of the magnet about below the card. The needle will be found to follow the magnet, proving that the magnet can attract a piece of iron or steel through cardboard. Repeat using the other end of the magnet. Try whether a magnet will attract iron or steel through other substances, such as paper, cloth, wood, copper (use the calorimeter employed in Exercise 132), iron (use a sheet of tinned iron).

5. Suspend the magnet by a double loop (p. 86) of unspun silk from a wooden stand, and notice that the magnet sets itself in a definite direction, which is approximately north and south, and that the same end always points north.

The Magnet.—The experiments made in the preceding exercise will give a general idea of the distinctive properties of a magnet. It will have been noticed that the power of attracting iron or steel bodies is chiefly concentrated near the ends of the magnet. The two points near the ends of the magnet at which we may suppose the magnetic power to be concentrated are called the *poles* of the magnet. The first four experiments made showed no difference between the two poles; the fifth experiment, however, shows a difference. That pole which, when the magnet is freely suspended, turns towards the north is called the north pole,[1] while the other is called the south pole.

EXERCISE 141.—*Lines of force of a magnet.*

Apparatus:—Iron filings; paraffin and flat dish; bar and horse-shoe magnets; small compass.

Melt some paraffin wax in a large flat dish—the top of a biscuit-box will do,—and dip a sheet of white unlined paper in the wax. Remove the paper, allow as much wax to drain off as possible, and hang up to cool. Treat half a dozen sheets in this way.

Lay a bar magnet on the table, and over it place one of the waxed sheets of paper, using two blocks of wood to support the paper. Then dust a thin layer of fine iron filings all over the paper. The filings can best be put on by means of a test-tube full of filings, with a piece of muslin tied over the end. Gently tap the paper, and notice how the filings set themselves in lines radiating from the two ends of the magnet. When these lines are as distinct as possible, pass a Bunsen flame rapidly over the surface of the paper. The wax will in this way be melted, and will serve to "fix" the filings.

Place a very small compass in different positions on the sheet of paper, and notice that in every case the needle sets itself parallel to the lines formed by the iron filings. Thus the curved lines in which the filings set themselves, when the paper is tapped so that they are free to move, represent the directions in which a small pivoted needle would set at each point. These curves are called the lines of force of the magnet, for they give at each point the direction in which the poles of a small needle would be pulled under the influence of the bar magnet.

[1] This pole of a magnet is sometimes called the north-seeking pole, and the other the south-seeking pole.

Obtain in the same way the lines of force of a horse-shoe magnet; of two bar magnets placed parallel and about two inches apart (1) with like poles turned the same way, and (2) with unlike poles turned the same way; and of two bar magnets placed so as to form a T, but with about an inch between the end of one magnet and the middle of the other.

EXERCISE 142.—*Lines of force of a magnet.*

Apparatus:—Large flat photographic dish; 12-in. bar magnet; sewing-needles and pieces of cork.

If it were possible to obtain either a north or a south pole alone, such a single pole when placed near a magnet would, if it were free to move, travel along a line of force. Although it is impossible to obtain a single pole, we may so arrange the experiment that one pole of a small magnet may be less affected by the magnet whose lines of force have to be studied than the other pole.

Magnetize a sewing-needle by stroking it from end to end with the pole of a bar magnet. Then stick this needle through a small disc of cork, so that the eye projects just above the surface of the cork. Fill a large photographic dish with water, and support a large bar magnet on blocks of wood just above the surface of the water.

Float the magnetized needle on the water with the eye uppermost, and see towards which pole of the bar magnet it is attracted. Then starting the floating needle near the opposite pole of the bar magnet, notice the path the needle follows while passing to the attracting pole of the magnet. Start the floating needle from different points, and in every case make a drawing of the path it follows. It will be found that these paths are of the same shape as the lines obtained with the iron filings.

EXERCISE 143.—*Method of magnetizing a steel strip, and magnetic repulsion.*

Apparatus:—Bar magnets; steel clock-spring.

Take a strip of clock-spring about 6 inches long, straighten it out, and fasten it to the top of the table with a *little* sealing-wax. Then stroke it from end to end with the north end of your bar magnet, being careful always to commence at the same end. Hold the magnet nearly vertical, and move it with a steady and uniform motion. Mark the end at which you began stroking the spring, and notice that it has become a magnet.

Make a double loop (see p. 86) in a length of *unspun* silk fibre, and by it hang the magnetized watch-spring from a wooden stand. There ought to be at least a foot of fibre between the stand and the loop. The magnetized spring will set itself with the marked end pointing north. Repeat the experiment, stroking the spring with the south pole of the bar magnet. In this case the end of the spring at which you begin stroking will be found a south pole. Mark the north pole of this strip, and then bring the north pole of the bar magnet near the north pole of the suspended magnet. What happens? Also test what happens when the north pole of the bar magnet is brought near the south pole of the suspended magnet. Repeat the experiments, using the south pole of the bar magnet. From your results draw up a rule for telling whether two poles will repel or attract one another. If the reason a suspended magnet sets itself north and south is because the earth is a large magnet, which attracts the poles of the suspended magnet, what kind of a pole must the earth have at the north pole?

EXERCISE 144.—*Method of magnetizing steel strips.*

Apparatus as in previous exercise.

Fasten a strip of clock-spring to the table, as in the previous exercise, and, holding a bar magnet in a nearly vertical position, in each hand place the south pole of the one and the north pole of the other in contact with the middle of the spring. Then draw the magnets away from one another till the end of the spring is reached. Repeat this operation several times, make a note of the position in which the magnetizing magnets have been held, and mark the right-hand end of the steel strip. Suspend the strip, and determine which end is the north pole. Hence give a rule for telling which end of the strip will be the north pole, illustrating your answer by means of a sketch.

EXERCISE 145.—*Method of magnetizing steel strips.*

Apparatus as in previous exercise.

Fasten a strip of clock-spring to the table, and, holding two bar magnets as in the previous exercise, place a small piece of wood about an inch wide between their poles, then move them from one end of the strip to the other. The poles of the magnets must be held against the piece of wood all the time, so that they may be separated by a constant distance.

Determine which end of the strip is a north pole, and draw up a rule as in the previous exercises, giving a lettered sketch.

EXERCISE 146.—*Effect of breaking a magnet.*

Apparatus:—Bar magnet; clock-spring; iron filings and paraffined paper.

Take a piece of clock-spring, about 3 inches long, and straighten it out. Wind one end of a piece of iron wire round the spring, and hold it in the flame of a large Bunsen burner till the whole length is at a bright-red heat. Then rapidly quench, by plunging into some cold water. In this way the steel will become very hard and brittle. Magnetize by the method used in Exercise 143 or 144, stroking the strip, first on one side, then on the other. Mark the north pole of the strip, and obtain the lines of force with iron filings. Also dip in iron filings, and note that none of the filings adhere to the middle.

Next break the magnetized strip in half, marking the parts, so that you will know which ends of the two pieces were next each other. Plunge each of the pieces in iron filings. Describe what happens, making a sketch of the tufts obtained (1) before, (2) after breaking.

Determine which ends of the two parts are north poles by suspending them, or trying their effect on a suspended needle, remembering that like poles repel, and unlike poles attract one another.

Hold the two halves in the position they occupied before the strip was broken, and plunge into filings. Notice that the tufts of filings are much greater at the ends than at the middle. Thus the two opposite poles which are in contact to a great extent neutralize each other's effect.

Break one of the halves in two, and repeat the tests. Again break one of these portions in two, and so on. It will always be found that each portion is a complete magnet with two poles, and that, when the parts are placed together, a magnet is obtained with a pole at each end, the intermediate poles practically neutralizing each other.

Terrestrial Magnetism.—In some of the preceding exercises it has been found that when a magnet is suspended by a fine thread, so that it is free to turn in a horizontal plane, it sets itself in a north and south direction. When suitable arrangements are, however, made so that the true geographical north is observed, *i.e.* the direction which points to the north end of the axis about which the earth turns, it is found that

a magnet does not point exactly due north. The angle included between the direction in which a freely suspended magnet points and the true north is called the *declination.* It is found that the declination varies from place to place on the earth's surface, and also changes with time. The value of the declination in Great Britain at the present day is about 20° W. —that is, the magnet points 20° west of true north.

If a magnet, instead of being suspended by a thread or mounted on a pivot so that it can only turn in a horizontal plane, is mounted on a horizontal axle so that it can turn in a vertical plane, then it is found that in the northern hemisphere the north pole points more or less downwards. If the needle is so placed that when it is horizontal it is pointing *magnetic* north and south, *i.e.* so that the axle points due magnetic east and west, then the angle which the needle makes with the horizontal is called the *inclination*, or *dip.* In the southern hemisphere the south pole of the needle would dip.

Magnetic Axis.—The straight line joining the poles of a magnet is called the *magnetic axis* of the magnet. The

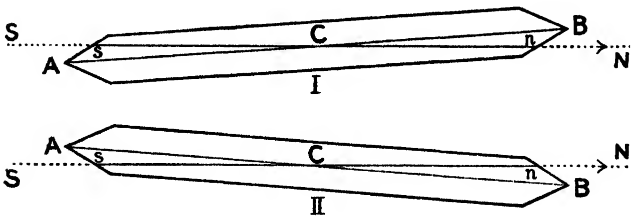

FIG. 99.

magnetic axis of a magnet need not, and, in fact, seldom does, exactly coincide with the straight line joining the centres of the end faces of the magnet, *i.e.* the geometrical axis. When determining the direction of the magnetic meridian, we can only observe the direction in which the geometrical axis of the suspended magnet points, while what is required is the direction in which the magnetic axis points.

If AB (I., Fig. 99) is a magnetic needle suspended at C, AB will then be the geometrical axis. Let the magnetic axis

of the needle be *ns*. Then the line *ns* will lie in the magnetic meridian, and if the line AB were taken, it is evident that this would lie to the west of north.

Suppose now the needle is reversed, so that what was the upper side is now the lower. Then, as is shown at II., the line AB is now just as much to the east of the magnetic meridian as it was before to the west. Thus, if we note the direction in which AB lies, both before and after reversal, the magnetic meridian will be half-way between these two directions.

EXERCISE 147.—*Magnetic axis.*

Cut a piece of paper into the shape of the needle AB (Fig. 99), and about four inches long. On each side of this paper draw the line AB, and a line *ns* to represent the direction of the magnetic axis. When held up to the light, you must not be able to see two lines *ns*, but they should lie exactly one over the other.

On a page of your note-book draw a line SN to represent the magnetic meridian, and, passing a pin through the centre C of the paper needle, fix it into the paper somewhere along the line SN. Turn the needle till the magnetic axis *ns* lies along this line, and mark the points where the ends A and B of the needle lie. Then reverse the needle, and turning it till the magnetic axis *ns* again lies along SN, mark the position of the ends. Remove the needle and join the points thus marked, and show by measurement that SN bisects the angle included between the two lines joining the positions of A and B.

EXERCISE 148.—*Magnetic axis of a magnetized disc.*

Apparatus:—Magnetized steel disc; large pins; stand.

You are supplied with a magnetized steel disc, and are required to find the direction of its magnetic axis. Suspend the disc by means of unspun silk so that it just hangs clear of the top of the table, and its surface is horizontal. Fix two large pins upright into the table approximately north and south, and at opposite ends of a diameter of the disc. When the disc comes to rest, make two marks on the upper surface opposite the pins. Then reverse the disc, and when it comes to rest again make two marks opposite the pins, but in this case on what is now the under surface of the disc. Remove the disc, and bisect the angle between the two diameters

which have been marked on the surface. This line of bisection will be the magnetic axis of the disc. Verify this fact by laying a sheet of paper over the disc, and using iron filings, as in Exercise 141. Show how it is that the above method gives the magnetic axis, illustrating your answer by diagrams.

EXERCISE 149.—*To find the magnetic meridian.*

Apparatus:—Bar magnet; cardboard; unspun silk; wooden stand.

Cut two pieces of thin cardboard, about 1 inch square. At the centre of one punch a hole about $\frac{1}{2}$ inch in diameter, and over this hole fasten two silk fibres forming a cross; at the centre of the other make a pinhole. Fix these cardboard squares to the ends of a bar magnet with soft wax, as shown at A and B in Fig. 100. Suspend the bar magnet from a *wooden* clamp or stand by

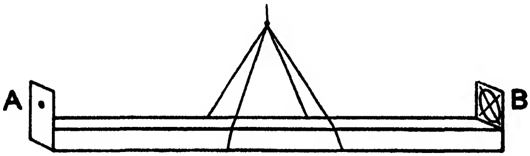

FIG. 100. ($\frac{1}{3}$.)

some unspun silk and a double loop, so that the magnet hangs about 2 inches above the surface of the table. Then, having removed any movable iron from the immediate neighbourhood, look through the pinhole A, and fix a large pin in the table at a distance of about 2 feet from the magnet, so that it appears in line with the point of intersection of the silk threads on the card B at the other end of the magnet. Without disturbing the stand from which the magnet is suspended, turn the magnet so that the surface which was next the table is now uppermost, and fix another pin in the line of sight past the intersection of the cross wires.

Make a mark on the table where the direction of the suspending fibre would meet the table. This may be done by removing the magnet, and then hanging a plumb-line from the point on the stand from which the magnet was suspended. Draw straight lines joining this point with the two pins, and bisect the angle between the lines. This bisector will give the direction of the magnetic meridian at the surface of the table.

If the suspending fibre is twisted an error will be introduced,

for the torsion will twist the magnet out of the magnetic meridian. This error may be reduced by using a long suspension fibre, and by hanging a bar of some non-magnetic metal of about the same weight as the magnet in the loop. When this metal bar comes to rest, turn the supporting stand till the bar points approximately north and south. Then replace the bar by the magnet, being careful not to allow the fibre to twist.

EXERCISE 150.—*Measurement of dip.*

Apparatus:—Dip needle and stand.

Set the edge of the stand of the dipping-needle (Fig. 101) parallel to the magnetic meridian found in the last exercise, so that the divided circle will lie north and south, and the axle of the needle point east and west.

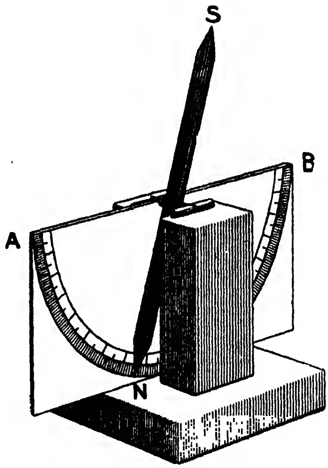

FIG. 101. ($\frac{1}{3}$.)

The dipping-needle itself consists of a strip of steel about 6 inches long, pointed at either end, and with a cylindrical steel axle passing exactly through the centre of gravity of the needle. This axle rests on two short pieces of glass rod fixed to the top of the uprights of the stand.

A graduated semicircle is fixed so that the diameter AB is just above the level of the top of the glass rods, a small semicircle being punched out to allow of the axle resting freely on the glass. This scale serves to measure the angle which the axis of the needle NS makes with the horizontal AB, *i.e.* the dip.

Place the needle on the glass rods, so that the axle is at right angles to AB, and passes through the centre of the hole punched in the card, and take the reading opposite the end N, being careful to avoid parallax. Then reverse the needle, so that the face which was next the card is now turned away from it, and again take the reading opposite N.

The mean of the two readings will allow for any error due to the magnetic axis of the needle, *i.e.* the lines joining the poles, not being parallel to the line joining the ends of the needle. This

reversal also in part eliminates any error due to the axle not exactly passing through the centre of gravity of the needle. This error may be completely eliminated by remagnetizing the needle so that what was a north pole is now a south pole, and repeating the readings. The mean of all four readings will then be the dip.

Magnetic Moment.—The experiments made in Exercise 146, on the effects of breaking a magnet, and then again building up the magnet with the parts, have shown that a north and south pole, when placed near together, tend to neutralize each other's effect on external bodies. It is thus evident, since every magnet must have both a north and a south pole, that these poles must, to some extent, tend to neutralize each other's effect. Hence, if we have two magnets, the poles of which are of equal strength, but one magnet is twice as long as the other, then the longer magnet will exert a more powerful effect on external bodies, since the two poles are further apart, and therefore do not neutralize each other's effect to so great an extent. For this reason, in order to have an idea of the strength of a magnet, we require not only to know the strength of the poles but also the distance between the poles. The product of the strength of either of the poles of a magnet into the distance between the poles is called the magnetic moment of the magnet.

EXERCISE 151.—*Comparison of magnetic moments by the deflection method.*

Apparatus:—Compass with index moving over divided circle; [1] metre scale; bar magnets.

Draw a line on the top of your table at right angles to the magnetic meridian marked in Exercise 149. Lay a metre scale along this line, and set the compass so that the centre is over the middle of the scale. Then, having removed all magnets and iron to a distance, turn the compass-box (not the scale) till the pointer comes to the zero of the circle. Place a bar magnet on each side of the compass-needle at a distance of not less than 20 cm., and adjust their positions till the needle of the compass comes back to zero.

[1] The compass belonging to the galvanometer described on p. 212 will do for this experiment.

The magnets must be placed with their axis east and west. Measure the distance between the centre of each magnet and the centre of the compass. Repeat the experiment, placing the magnets at different distances from the compass. Enter your results in a table as below, filling in the necessary data :—

Magnet No. I.		Magnet No. II.		
Distance from Compass $= d_1$.	Cube of Distance from Compass $= d_1^3$.	Distance from Compass $= d_2$.	Cube of Distance from Compass $= d_2^3$.	$\frac{d_1^3}{d_2^3}$

It will be found that the numbers in the last column are constant. They represent the ratio of the magnetic moments of the two magnets, and the experiment shows that the turning effect on the needle produced by a magnet varies inversely as the cube of the distance of the magnet from the needle. Repeat the experiment, turning the metre scale into the meridian, and placing the bar magnets north and south of the compass.

Induced Magnetism.—Both soft iron and steel are attracted by a magnet; there is, however, an important difference between the magnetic properties of these two substances. When a piece of steel is stroked by a magnet, it has been found that it becomes magnetized, and, further, that it retains this magnetism. If, on the other hand, an attempt is made to magnetize a piece of iron by any of the methods given in some of the previous exercises, it will be found that the iron, particularly if it has been well annealed, will not retain any of the magnetism imparted to it. Although it is impossible to permanently magnetize a piece of soft iron, such a piece of iron becomes temporarily magnetized, when a magnet is brought near it. In the same way, a piece of hard steel, when brought near a magnet, becomes magnetized, though not so easily as a piece of soft iron; it, however, retains its magnetism after the removal of the magnetizing magnet.

EXERCISE 152.—*Induced magnetism in iron and steel.*

Apparatus:—Bar magnet; piece of soft iron and of steel; iron filings and paraffined paper; compass.

Place a piece of soft iron, about 3 inches long, and of the same cross-section as the bar magnet supplied to you, under a sheet of paper, and test whether it is magnetized by means of iron filings. Also bring it near a suspended or pivoted magnetic needle, and notice that either end *attracts* each end of the needle.

Next place the soft iron and the bar magnet in line, separated by about half an inch, and obtain the lines of force with filings, in the manner described in Exercise 141. To what conclusion as to the state of the soft iron when near the magnet do the lines of force lead? From the directions in which the lines of force run, can you, by comparing these curves with those obtained in Exercise 141, tell which end of the iron has a pole of the same sign as the nearer pole of the bar magnet?

Remove the bar magnet, and again test the magnetic condition of the soft iron by means of a suspended or pivoted magnet.

Repeat the experiments, using a piece of unmagnetized soft steel in place of the soft iron. In what way do the results now obtained (1) when the bar magnet is near, and (2) after the removal of the bar magnet, differ from those obtained with the soft iron? Make a lettered sketch, showing which end of the steel has a north and which a south pole when placed opposite (1) the north pole, and (2) the south pole of the bar magnet.

EXERCISE 153.—*Induced magnetism.*

Apparatus:—Bar magnet; small magnet; piece of soft iron wire; compass.

Take a piece of soft iron wire about 3 inches long, and hold it in a vertical position with the lower end near one of the poles of a pivoted magnetic needle. Bring a bar magnet, with its north pole downwards, near the upper end of the wire, and notice which pole of the pivoted needle is repelled by the lower end of the wire. Hence determine the sign of the pole at the lower end of the wire. Repeat, bringing the south pole of the bar magnet near the top of the wire. Make two sketches, showing the arrangement of magnet and wire, lettering the poles of the magnet and the pole induced at the lower end of the wire.

Next tie a piece of cotton to one end of the iron wire, place the bar magnet on the table, and, holding the cotton by the end, bring the wire near one pole of the magnet, but do not let the end of the

wire quite touch the pole. The position in which the wire is to be placed is shown in Fig. 102. Here NS is the bar magnet, AB the

FIG. 102.

wire, and CB the cotton, which is held at C, the attraction of the magnet keeping the wire in an almost horizontal position. The experiments already made have shown that a north pole is induced in the iron wire at B; we now have to show that a south pole is induced at A.

Holding a small magnet horizontal, and at right angles to the bar magnet, bring the south pole near A. It will be found that the wire is repelled, showing that a south pole has been induced at A. Bring the south pole near B, and attraction will take place.

Repeat, using the south pole of the bar magnet to induce the magnetism in the wire. Make in each case a diagram, on which the signs of the poles of the bar magnet and of the induced poles are clearly marked.

EXERCISE 154.—*Magnetism induced by the earth's field.*

Apparatus:—Bar of soft iron about 3 feet long (a poker); hammer; compass.

Place a suspended or pivoted needle near that edge of a table, which lies in about the magnetic meridian. Then holding a bar of iron, such as a poker, in the direction in which the dip-needle points (Exercise 150), bring first the top and then the bottom end near the pivoted needle. Carefully note the sign of the polarity induced in the poker. Reverse the poker, and repeat.

Next, holding one end of the poker near the pivoted needle, turn the poker about this end as a centre, keeping it in the magnetic meridian. Note the polarity of the end next the needle for different positions of the poker. Make a sketch, showing the polarity induced in the poker in the different positions, and give an explanation, remembering that the earth may be regarded as a large magnet with its south pole near the north geographical pole, and its north pole near the south geographical pole.

Hold the poker parallel to the direction of the dipping needle, and give it two or three sharp blows. Notice that the induced magnetism is much stronger than before. Hence concussion assists the magnetization of the iron by induction.

PART IX.—ELECTRICITY.

SECTION I.—STATIC ELECTRICITY.

IN order to insure success in many of the experiments on static electricity, it is essential that all the apparatus as well as the air of the room should be dry. For this reason the experiments generally succeed best on a frosty day. A bright open fire is the best means of drying electrical apparatus. Failing this, a large radiating gas stove, such as is used for heating purposes in shops, may be used.

EXERCISE 155.—*Electrification by friction.*

Apparatus:—Rods of sealing-wax, ebonite,[1] shellac, glass; flannel and silk rubbers.

Tear some paper into small pieces about half a centimetre square, and place these on the table. Rub a stick of sealing-wax with a dry piece of flannel or on your coat sleeve, and hold it over the pieces of paper. Notice that the paper is attracted, some of the pieces sticking to the sealing-wax, others dancing up and down between the rod and the table. Pass your hand over the surface of the sealing-wax, or pass the rod *rapidly* through a Bunsen flame. Again hold the rod over the pieces of paper. No attraction will take place. When the rod is rubbed, it is said to become *electrified*, and it is to this electrification that it owes its power of attracting the paper. Passage through the fingers or through a flame destroys the electrification. Try whether an electrified rod of sealing-wax will attract other light bodies, such as bran, pith, small chips of wood, cork, feathers, etc.

Repeat the experiment, using rods of ebonite, shellac, and glass. In the case of glass, use a rubber made of silk in place of the flannel.

[1] Ebonite stirring-rods may be obtained from chemical apparatus dealers at half a crown a dozen.

EXERCISE 156.—*Electrical attraction.*

Apparatus:—Rods of sealing-wax, ebonite, wood, steel, brass, etc.

Bend a piece of thick copper wire into the shape shown in Fig. 103, and suspend it by means of a thin piece of cotton from a retort-stand ring, thus forming a stirrup.

In the last exercise it was found that an electrified rod attracted light bodies, such as paper, pith, etc. An electrified body also attracts heavy bodies, but the attraction is not sufficiently strong to lift them up. In order to show that this is so, place a pencil in the stirrup, and bring an electrified rod of sealing-wax or ebonite near one end. It will be found that the pencil is attracted. Place an electrified rod in the stirrup, and bring the finger or the pencil near one end, the electrified rod will immediately be attracted. Thus not only does the electrified body attract the pencil, but the pencil attracts the electrified body.

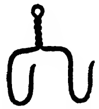

FIG. 103. ($\frac{1}{10}$)

Repeat the experiment, using rods of iron, steel, brass, etc., in place of the pencil, and show that they are all attracted by, and attract an electrified body.

EXERCISE 157.—*Positive and negative electrification.*

Apparatus:—Rods of sealing-wax, ebonite, glass, shellac; flannel and silk rubbers.

Electrify a rod of sealing-wax by rubbing with flannel, and place it in the stirrup. Then electrify a second rod of sealing-wax, and bring it near the end of the suspended rod. Notice that, instead of attraction, you get repulsion.

Electrify rods of ebonite and shellac, and find whether they attract or repel an electrified rod of sealing-wax. Also suspend electrified rods of ebonite and shellac, and try the effect of bringing electrified rods of sealing-wax, ebonite, and shellac near.

Next suspend an electrified rod of sealing-wax, and electrify a rod of glass[1] by rubbing with warm silk. Bring the electrified rod of glass near the electrified rod of sealing-wax. In this case attraction, and not repulsion, will take place. It is thus evident that the electrification induced in a glass rod when rubbed with silk is different from that induced in sealing-wax, for two electrified rods of sealing-wax repel each other, while an electrified rod of glass attracts an electrified rod of sealing-wax.

[1] The glass must be warmed in order to obtain satisfactory electrification.

Suspend an electrified rod of glass by the stirrup, and electrify a second rod of glass, and bring it near the suspended rod. In this case repulsion will take place.

Try whether an electrified rod of shellac or of ebonite attracts or repels an electrified rod of glass.

From the results of your experiments fill in the following table, in each square entering whether the two bodies, one of which is entered at the top of the column and the other at the end of the row in which the square lies, attract or repel each other when electrified in the manner indicated.

	Sealing-wax rubbed with Flannel.	Ebonite rubbed with Flannel.	Shellac rubbed with Flannel.	Glass rubbed with Silk.
Sealing-wax rubbed with Flannel ..				
Ebonite rubbed with Flannel ..				
Shellac rubbed with Flannel ..				
Glass rubbed with Silk ..				

Positive and Negative Electrification.—In the previous exercise it has been found that the electrification induced in glass, when rubbed with silk, differs from that induced in sealing-wax, ebonite, or shellac, when rubbed with flannel. For while two electrified rods of any one of these materials repel one another, and two electrified rods, one of which is of sealing-wax and the other of ebonite or shellac, also repel one another, an electrified rod of glass attracts an electrified rod of either of the other materials.

These two kinds of electrification have received separate names: that which is developed in sealing-wax, shellac, and ebonite, when rubbed with flannel is called *resinous*, or *negative*, electrification, while that developed in glass when rubbed with

silk is called *vitreous*, or *positive*, electrification. For convenience in writing, resinous or negative electrification is indicated by the symbol – (minus), and vitreous or positive electrification by the symbol + (plus).

It will be seen that the results obtained in Exercises 155-157 can be summarized as follows:—

All electrified bodies attract all unelectrified bodies.

Bodies electrified with the same kind of electrification repel one another.

Bodies electrified, one positively and the other negatively, attract one another.

EXERCISE 158.—*Electrification by contact with an electrified body.*

Apparatus:—Pith ball; unspun silk; rods of ebonite or sealing-wax and glass; flannel and silk rubbers.

Suspend a pith ball by a thread of unspun silk,[1] and bring an electrified rod of sealing-wax or glass near it. The pith ball will be attracted, but if allowed to touch the rod it will immediately be repelled.

It will be found that the ball has now acquired the power of attracting unelectrified bodies. Hold your hand near the ball, and notice that it is attracted. The ball has thus become electrified or charged by contact with the rod, and since when it is electrified it is repelled by the rod by which it was electrified, it follows that its electrification is of the same kind as that of the rod. Bring a rod electrified with the opposite kind of electrification to that of the charging rod near the charged pith ball and show that it is attracted.

EXERCISE 159.—*Conductors and insulators.*

Apparatus as in previous exercise, with the addition of small disc of metal.

Suspend a pith ball by a length of cotton, and bring an electrified rod near it. The pith ball will be attracted, and after contact with the rod will fall back. On bringing an unelectrified body near the ball no attraction will take place, and the ball will be found quite unelectrified. We thus see that the charge communicated to the pith ball by contact with the electrified rod has been lost. Since

[1] All silk used for insulation purposes must be undyed.

the only way in which the pith ball now used differs from that used in the previous exercise, which was found to retain its charge, is the suspending fibre, we are led to the conclusion that, while silk does not allow the electrification of the pith ball to escape, cotton does.

A body such as cotton, which allows the electrification to escape, is called a conductor.

Fasten a small piece of metal, such as a half-penny, on the end of a stick of sealing-wax. Holding it by the sealing-wax, charge the half-penny by contact with an electrified body. Then bring the charged half-penny near a suspended pith ball, and notice that the charge is retained for a considerable time. Repeat the experiment, using rods of ebonite, shellac, glass, wood, and metal as handles to support the half-penny, and find in each case whether, when so supported, it retains its charge.

Insulators and Conductors.—From the results obtained in the last exercise it will be noticed that, while some bodies, such as silk, sealing-wax, ebonite, etc., do not allow the electrification of a body which they support to flow away, other bodies, such as cotton, wood, metal, etc., allow the electrification to escape. Bodies which do not allow the electrification to escape are called nonconductors, or insulators, since they may be used to insulate an electrified body so that its electrification will not escape. Bodies which allow the electrification to escape are called conductors, since they are supposed to conduct the electrification away.

The Proof Plane.—In the subsequent exercises we shall often make use of a small disc of metal, about the size of a sixpence, attached to an insulating handle, made of ebonite or sealing-wax, about six inches long. This instrument is called a proof plane. When the metal disc is brought in contact with an electrified body it becomes charged with the same kind of electricity as is the body at the point of contact. If we then remove the proof plane by the insulating handle, and test the quantity and sign of the electrification carried away, we can obtain a measure of the kind and quantity of the electrification of that part of the charged body at which contact was made. If it is found that the proof plane rapidly loses its charge, the

handle must be dried by passing it through a Bunsen flame. The handle ought always to be held as near the end as possible.

EXERCISE 160.—*The proof plane.*

Apparatus as in previous exercise, with the addition of a proof plane.

Suspend a pith ball by about a foot of silk, and charge it negatively by contact with an electrified rod of sealing-wax or ebonite. Then charge the proof plane negatively by contact with the electrified sealing-wax, and bring the metal disc near the pith ball. The ball will be repelled. Next charge the proof plane positively, by means of a glass rod rubbed with dry silk, and again bring the disc near the pith ball. The ball will in this case be strongly attracted. The ball will also be attracted if the proof plane is uncharged, but not so strongly. Devise some experiment in which a repulsion is obtained for showing conclusively that the proof plane is charged positively.

EXERCISE 161.—*Induction.*

Apparatus as in previous exercise.

Suspend an uncut wooden pencil by two loops of silk ribbon about a foot long. The pencil will thus be insulated. Electrify a rod of sealing-wax (or ebonite), and holding it about half an inch *under* one end of the pencil touch the other end of the pencil with the proof plane. Remove the proof plane, being careful to keep the sealing-wax in place till the proof plane has been removed, and also not to allow the sealing-wax to touch the pencil, or to come so near as to allow a spark to pass. The passage of a spark will be indicated by a slight click.

Test the charge taken away by the proof plane by means of a charged pith ball, as in the last exercise. It will be found to be charged negatively, *i.e.* with the same kind of electrification as the electrified rod.

Next repeat the experiment, touching the insulated pencil at the end at which the electrified body is placed, and again test the charge carried away by the proof plane. In this case the charge will be positive.

Repeat the experiment, making contact at the middle of the pencil. The proof plane will in this case receive no charge, indicating that the middle of the insulated pencil is unelectrified.

The pencil must be discharged before each experiment by being touched with the finger.

Bring the electrified rod of sealing-wax near the pencil, and then take it away, and test whether any part of the rod is now electrified.

Repeat the whole series of experiments, using a positively electrified rod of glass in place of the negatively electrified rod of sealing-wax.

Make sketches of the pencil and charged rod in the two cases, and clearly mark the sign of the electrification on the charged rod (sealing-wax or glass), and also the signs of the electrification at the different parts of the insulated conductor (pencil).

Induction.—The experiments made in the preceding exercise have shown that, when a charged body is brought near an insulated unelectrified conductor, this conductor becomes electrified. The conductor is in such a case said to be electrified by *induction*, and the charge which is developed is called the *induced charge*, and the electrified rod is called the *inducing body*. The experiments have also shown that the electrification induced in the conductor is at the end nearer the inducing body of the opposite sign to the inducing charge, while the electrification at the further end of the conductor is of the same sign as the inducing charge.

Since, when the inducing charge is removed the insulated conductor shows no signs of electrification, it follows that the induced (positive and negative) electrification must, on the removal of the inducing charge, mutually destroy one another.

EXERCISE 162.—*Induced charge.*

Apparatus as in previous exercise.

Bring an electrified stick of sealing-wax (or ebonite) near the end of the insulated pencil, as in Exercise 161, and, while the inducing body is in place, momentarily touch any part of the pencil with your finger so as to connect the insulated body with the earth; such an operation will, in future, be referred to as "putting the insulated body to earth." Now remove the inducing charge, and touch the insulated pencil with the proof plane, and determine, by means of a charged pith ball, whether a charge is taken away, and, if so, of what sign.

Repeat the experiment, using a positively electrified body (glass) to induce the charge.

"Bound Charge" and "Free Charge."—The preceding experiment has shown that the state of the two kinds of electrification induced in an insulated conductor, when a charged body is brought near, are different. For on putting the insulated body to earth the charge of the same sign as the inducing charge, which is driven to the opposite end of the conductor from the inducing charge, escapes; while the charge of the opposite sign, which is accumulated on the end of the conductor nearest the inducing charge, remains on the conductor even when this latter is connected to earth. The first of these charges, which escapes when the insulated conductor is put to earth, is often spoken of as the "free charge," while that which does not escape is called the "bound charge."

The results of the experiments may be summed up by saying that, when a charged body, A (Fig. 104), is brought near an insulated conductor, BC, a charge of opposite sign to the inducing charge is attracted to the part of the conductor nearest the inducing charge, while a charge of the same sign is driven away to the part of the conductor furthest away from the inducing charge. When the insulated conductor is put to earth, then for the time being the earth forms part of the conductor, and thus the charge of the same sign as the inducing charge travels away to the opposite end of the earth.

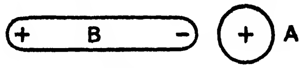

FIG. 104.

EXERCISE 163.—*Induced charge on an uninsulated body.*

Apparatus as in previous exercise.

From what has been said in the previous paragraph we should expect that, when a charged body is brought near an *uninsulated* body, a charge of opposite sign would be induced in the part of the uninsulated body nearest the charged body.

In order to prove that this is so, charge a rod of sealing-wax or glass, and, holding it about an inch above the surface of the table, touch the table with the proof plane just below the electrified rod. Test the charge carried away by the proof plane, and show by a sketch the sign of the charge induced in an uninsulated body when

(1) a positively and (2) a negatively electrified body is brought near. Why must you remove the proof plane from the table *before* you remove the inducing charge?

The Gold-leaf Electroscope.—In some of the preceding exercises we have made use of a suspended pith ball as a means of detecting whether a body is or is not electrified. A more sensitive and convenient instrument to use for this purpose is shown in section in Fig. 105, and is called a gold-leaf electroscope. It consists of a metal disc, A, connected by a metal rod with a small metal cross-piece, B. Two strips of gold leaf, C, are attached to this cross-piece. The metal rod connecting the disc with B is insulated by being surrounded with sealing-wax (shown shaded at D in the figure), where it passes through the cork E. This cork fits into the neck of a wide-mouthed bottle, which serves to protect the gold leaves from draughts. When a charge is communicated to the metal plate A, called the cap, the gold leaves also become charged, and as they are charged with the same kind of electricity they repel one another; the stronger the electrification the greater is the divergence of the leaves.

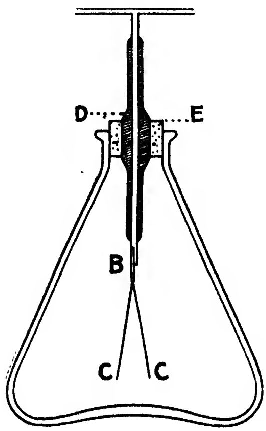

FIG. 105. (¼.)

By bringing a body in contact with the cap of an uncharged electroscope we can see whether it is charged or not, and also get an idea as to the extent to which it is charged, but we cannot tell the sign of the charge. If, however, the electroscope is charged, say positively, so that the leaves are moderately diverged, then, by bringing a positively electrified body *near* the cap, a negative charge will be induced at the cap, while an induced positive charge will be repelled to the gold leaves, causing them to diverge further. If, on the other hand, the charged body is electrified negatively, then on bringing

it near the cap an induced negative charge will be repelled down to the gold leaves, which will either partly or wholly neutralize the positive charge, and therefore cause the leaves to collapse. It is important that the charged body should be brought near the cap slowly, and the gold leaves watched the while; for if the body is strongly negatively electrified, it is possible that when it is near the cap the negative charge repelled to the gold leaves may be so strong as not only to neutralize the existing positive charge, but also to cause the leaves to diverge further than before; this time, however, with a negative charge.

EXERCISE 164.—*The gold-leaf electroscope.*

Apparatus:—Gold-leaf electroscope; rods of glass and ebonite or sealing-wax; silk and flannel rubbers.

Charge the electroscope (say) positively, so that the ends of the gold leaves are separated by about an inch. There are two methods which can be employed for this purpose: (i.) rub a glass rod with dry silk, and then communicate some of the charge to the electroscope by touching the cap with the charged rod; and (ii.) electrify a rod of sealing-wax or ebonite negatively by rubbing with flannel, and hold this rod so near the cap that the leaves diverge to a little more than the required amount. Then keeping the charged rod in place, put the cap to earth (p. 194). On removing the charged rod the leaves will diverge, being now charged positively by what was the "bound" charge.

Electrify the electroscope (1) positively, (2) negatively, by each of these methods, testing whether the charge communicated is really of the desired sign by bringing a positively (glass) or negatively (sealing-wax) electrified rod *near* the cap. Write a description and make sketches illustrating (1) the method of charging and (2) the method of testing the sign of the charge.

It will be found best in subsequent experiments, unless for any special reason a negative change is required, to always charge the electroscope positively; and it will generally be found easier to charge by the induction method (ii.), since it is easier to electrify sealing-wax or ebonite than glass. Practise charging the electroscope till you can make certain of charging it with the required kind of electrification.

EXERCISE 165.—*The gold-leaf electroscope.*

Apparatus as in previous exercise.

Charge the gold leaf electroscope somewhat strongly, and bring the hand near, but not touching, the plate. Notice how the leaves collapse. This collapse is due to the charge induced on the under surface of the hand reacting on the inducing charge and attracting it to the upper surface of the cap, so that the electrification of the leaves is reduced. How would you distinguish the collapse of the leaves produced in this way by an uncharged body from that produced by a body charged with electrification of the opposite sign to that with which the electroscope is charged?

EXERCISE 166.—*Conduction.*

Apparatus as in the previous exercise, with the addition of rods of wood, etc., and lengths of wire, cotton, silk, etc.

Charge the electroscope so that the leaves diverge widely, then touch the cap with the end of a length of about a foot of the following substances, holding the other end in your hand: metal wire, wood, dry silk, damp silk, cotton, glass rod on the surface of which you have breathed, the same rod after the surface has been well dried. Note in each case the time the leaves take to collapse owing to the charge being conducted along the different substances. Draw up a table in which these substances are arranged in order, the best conductors coming first.

The Electrophorus.—When we charge a conductor by touching it with an electrified insulator, such as sealing-wax or glass, only the electricity quite near the point of contact is able to escape on to the conductor. The rest of the electrification, since it cannot flow from one part of the insulator to another, does not go to charge the conductor. By making use of the induction exercised by a charged body on a conductor we can not only make use of the whole electrification, but we can charge a conductor again and again without dissipating the inducing electrification. An instrument which works on the induction principle, called an electrophorus, is shown in section in Fig. 106. It consists of a disc of ebonite, shellac, or indiarubber, AB, on the bottom surface of which a disc of tinfoil, CD, is pasted.

A disc of metal, EF, with a rounded edge, and fitted with an insulating handle made of a rod of sealing-wax or of varnished glass, forms the conductor on which the charge is induced.

When the upper surface of AB is rubbed with a dry flannel it becomes negatively electrified. This negative electrification induces a positive electrification on the tinfoil CD, the corresponding negative electrification flowing to earth if the instrument is standing on the table. This charge induced on the tinfoil reacts on the charge on AB, and tends to prevent it flowing away. If now the plate EF is placed on AB, since the surfaces of EF and AB are neither of them absolutely flat, they only touch at a few points, and it is only the nega-

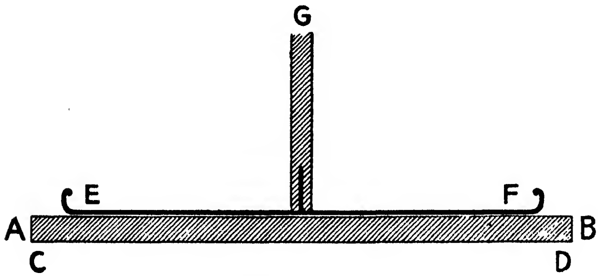

FIG. 106. (1/5.)

tive electrification at these few points which charges EF. All the rest of the electrification, however, induces an electrification in EF, positive on the lower surface and negative on the upper surface. If the plate is now removed and tested the two induced charges will have recombined, and only the very feeble negative charge conducted from AB at the points of contact will remain. Of the two electrifications induced when EF is placed on AB, one (the negative) is "free," while the other (the positive) is "bound." Hence, if the plate EF is put to earth by touching it with the finger, the negative "free" charge will escape, while the positive "bound" charge will remain. On now removing EF by means of the insulating

handle, it will be found to be strongly electrified with a positive charge, so that on approaching the finger or any other uninsulated body a strong spark will be obtained.

EXERCISE 167.—*The electrophorus.*

Apparatus:—Electrophorus; gold-leaf electroscope; rod of ebonite or sealing-wax.

Electrify the insulating disc of the electrophorus by sharply rubbing it with dry flannel, and test the sign of the charge by bringing the disc near an electrified electroscope. Discharge the plate EF (Fig. 106) by putting it to earth, and, holding the handle G near the end so that there may be as great a length as possible of insulating material between your hand and the plate, place the plate on the top of the electrified disc. Without touching the plate, remove it and test its electrical charge by means of a charged electroscope. Make a note of the amount and sign of the charge.

Replace the plate on the electrified disc, and this time put it to earth by touching it with your finger. Remove the plate by the insulating handle, and test the sign of the charge by carefully bringing it near a charged gold-leaf electroscope. Is the charge of the same or of opposite sign to the charge on the electrified disc? Has the plate been charged by conduction or by induction?

Bring your finger near the charged plate, and note the spark which passes.

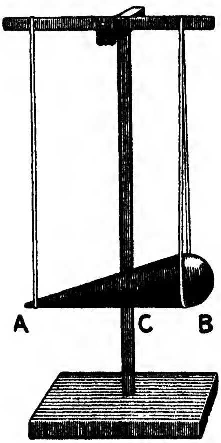

FIG. 107. ($\frac{1}{8}$.)

EXERCISE 168.—*Electric density.*

Apparatus as in previous exercise, with the addition of conductors of various shapes and proof plane.

Suspend a cone-shaped conducting body by two loops of silk, in the manner shown in Fig. 107. Charge the conductor by giving it two or three sparks from the electrophorus. Place the proof plane against the point A, then test the amount of the charge carried away by placing the proof plane flat on the disc of the electroscope, which for this experiment must be uncharged. Note the extent to which the

leaves diverge. Discharge the proof plane and electroscope, and in the same way find the amount of the divergence produced when the proof plane has touched the charged conductor at B and C. Make a drawing of the conductor, and indicate the amount of the charge at different parts by drawing a dotted line round the outline of the conductor, as in Fig. 108, so that the dotted line is furthest from the conductor at the parts where the charge is greatest.

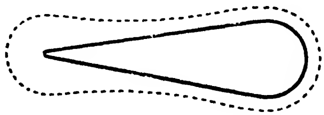

FIG. 108.

Repeat the experiment, using charged conductors of various shapes, such as a sphere, a cylinder with rounded ends, a disc, etc.

Electric Density.—The experiments made in the preceding exercise show that when an insulated conductor is charged, the charge is not always equally distributed over the surface of the conductor, but tends to accumulate at all projecting edges and points. This fact is referred to by saying that the *electric density* is greater near the projecting edges and points of a charged conductor.

EXERCISE 169.—*Distribution of charge on a hollow conductor.*

Apparatus:—Insulated tin vessel; electrophorus; electroscope; proof plane.

You are supplied with a metal vessel about 6 inches deep and 3½ inches in diameter, either carried on an upright rod of sealing-wax, or with a sheet of ebonite on which it may be insulated. Charge this vessel by giving it several sparks from the electrophorus plate, and then touch the bottom of the inside with a proof plane. Remove the proof plane, being careful not to touch any part of the vessel while doing so, and test whether it has brought away any charge. Also touch the inside of the side near the bottom, and see if the proof plane brings away any charge.

Next touch different parts of the outside with the proof plane, and test for electrification.

Charge the proof plane as strongly as possible with the electrophorus, then touch the bottom of the inside of the vessel. Remove the proof plane, and test whether it is charged.

To what conclusions do your results lead as to the distribution of the charge on a solid conductor?

Exercise 170.—*Faraday's ice-pail experiment.*

Apparatus as in previous exercise, with the addition of a conducting sphere.

Connect the edge of the insulated metal vessel used in the last exercise with the cap of the electroscope by means of a fine meta wire. This wire must not touch any other body besides the electroscope and the insulated vessel. Suspend a metal sphere,[1] about 1 inch in diameter, from a length of silk ribbon.

1. Charge this sphere by means of the electrophorus, and then holding it by the silk ribbon, lower it into the metal vessel, but do not let it touch either the side or bottom. Notice how the leaves of the electroscope diverge, but collapse on the removal of the sphere. Write out an explanation, illustrated by a sketch, of the reason the leaves diverge.

2. Again charge the sphere and introduce it into the vessel, as before, being careful not to touch the sides or bottom. While the charged sphere is in this position put the electrometer and vessel to earth by touching either with your finger. Note that the leaves collapse. Remove the sphere, the leaves will then diverge as much as before. Test the sign of the charge by bringing a negatively charged stick of sealing-wax near the cap of the electrometer. Write out an explanation of what you observe.

Equality in the Positive and Negative Charges produced by Induction.—The results of the above experiments with the charged sphere and the hollow conductor are practically the same as those obtained in Exercise 161, only the method of carrying out the experiments is slightly different. The positively charged sphere, when introduced into the metal vessel, induces a negative charge on the inside, and a positive charge is repelled to the other extremity of the conductor, *i.e.* to the electroscope. On putting the electroscope to earth this positive charge, since it is "free," escapes. When the inducing charge on the sphere is removed, the negative charge, which was "bound," spreads all over the conductor, and the gold leaves diverge with a negative charge. These experiments are only qualitative—that is, they only show that both positive and negative electrifications are developed by induction. The experiment can, however, be arranged in such a

[1] A wooden sphere coated with tinfoil will do.

way as to show that the amount of the negative induced charge is exactly equal to that of the positive induced charge, and that each of these charges is equal to the inducing charge.

EXERCISE 171.—*Equality of the positive and negative induced charges.*

Apparatus as in previous exercise.

Bring the charged sphere into the metal vessel, and put the electroscope and vessel to earth. Remove the sphere, but do not discharge it; the leaves diverge with the negative induced charge. Again introduce the charged sphere, and bring it into contact with the inside of the vessel. The leaves of the electroscope do not diverge. Remove the sphere, it will be found to have entirely lost its charge. Thus the positive charge on the sphere has exactly neutralized the induced negative charge, and this experiment therefore shows that the induced negative charge is exactly equal in amount to the inducing positive charge.

Next introduce the charged sphere, and, *without* putting the electroscope to earth, allow the sphere to touch the inside of the vessel. It will be found that the divergence of the gold leaves remains unaltered. The sphere will have communicated its entire charge to the vessel and electroscope, and this charge produces the same divergence of the leaves as did the positive induced charge. Hence the positive, and therefore also the negative, charge is exactly equal to the inducing charge when, as in this case, the body on which the charge is induced practically completely surrounds the inducing charge. Write out an account of the experiment, under the three heads: (1) the object of the experiment, (2) the method of carrying out the experiment, (3) explanation of the results obtained.

EXERCISE 172.—*Electric screening.*

Apparatus:—Electrophorus; electroscope; wire gauze.

In carrying out some of the previous experiments, it may have been found that when the electrophorus was placed too near the electroscope the leaves of the latter diverged when the electrophorus was used. This is due to the electrification induced in the electroscope by the powerfully charged plate of the electrophorus. It is often important to be able to screen an instrument, such as the electroscope, from the inductive effects due to charged bodies in the neighbourhood. In order to show how this may be done,

take some wire gauze and bend it into a cylinder, so that it will surround the electroscope and stand about 6 or 8 inches above the top of the plate. Connect this wire gauze with the gas-pipe by means of a metal wire, so that the gauze may be in good conducting communication with the earth. Now bring the charged electrophorus plate near the electroscope, and notice that the leaves are not affected. Holding the charged plate in position, remove the gauze, and notice the wide divergence of the electroscope leaves.

When placed between the charged body and the electroscope, the gauze has a charge induced on it of the opposite sign to the inducing charge, the corresponding induced charge of the same sign flowing to earth. This "fixed" charge, since it is of opposite sign to the inducing charge, tends to induce a charge on the electroscope of opposite sign to that which the charged body would induce. These two induced charges on the electroscope neutralize one another, and the electroscope is unaffected by the charged body. Disconnect the gauze from the wire leading to the gas-pipe, and insulate the gauze by standing it on a sheet of ebonite. Again bring the charged plate near, and notice that the electroscope is now affected. In this case the "free" induced charge cannot escape to earth, and so affects the electroscope by induction.

EXERCISE 173.—*To make a Leyden jar.*

Carefully clean and dry both inside and out a wide-mouthed glass bottle. Coat the inside and outside up to the shoulder with tinfoil, using shellac varnish[1] to stick on the foil. Then warm the upper part of the bottle, and give the portion of the glass which is not covered with tinfoil a thin coating of shellac varnish. When this varnish is dry set a piece of wood, in which a wire with a ring or knob at the top has been fixed, at the bottom of the bottle, and fasten it in position by pouring some plaster of Paris on the top. Pack the bottom of the bottle with scrap tinfoil, so as to connect the inside coating with the upright wire.

EXERCISE 174.—*The Leyden jar.*

Apparatus:—Leyden jar; electrophorus.

Holding the outside of a Leyden jar in your hand, charge the jar by passing two or three sparks from the electrophorus to the knob. Hold one end of a short piece of thick copper wire against

[1] Shellac varnish may be prepared by dissolving flake shellac in methylated spirit. The shellac takes some days to dissolve.

the outer coating, and bring the other end near the knob. Notice the difference in the character of the spark obtained and that obtained from the electrophorus. Charge the jar by a few sparks, and, holding the outside coating in one hand, bring the other hand near the knob. Notice the shock felt, due to the combination through the body and arms of the charge on the inside coating, and the induced charge on the outside coating.

Charge the Leyden jar and stand it on a sheet of ebonite. Touch the knob with your finger, a slight spark will be obtained. Lift the jar by the *knob*, and, holding one end of a piece of wire against the *knob*, bring the other end near the outside coating. A strong spark will now be obtained.

When the inside coating of a jar is charged, the "free" induced charge on the outside coating escapes to earth, while the "bound" charge remains and attracts the inducing charge. When the jar is placed on an insulating stand and the knob touched, the charge on the outside coating now holds most of the charge on the inside coating bound.

SECTION II.—VOLTAIC ELECTRICITY.

EXERCISE 175.—*Voltaic cell.*

Apparatus:—Sulphuric acid; mercury; beaker; copper and zinc foil; rod of pure zinc; copper wire.

Make a dilute solution of sulphuric acid by pouring 20 c.c. of strong sulphuric acid into 200 c.c. of water. Be careful to add the sulphuric acid to the water.[1] Dip a rod of pure zinc in the dilute acid, and note that it is not eaten away. Use a rod or plate of commercial zinc in place of the pure zinc, and note that it is eaten away, bubbles of gas being evolved.

Take the rod out, and dip it into some mercury,[2] and rub the surface with a cork till it is covered *all* over with coating of mercury. Replace the zinc in the dilute acid, and note that it is no longer eaten away. The effect of coating the zinc with mercury (amalgamation) is to make the behaviour of the impure zinc resemble that of pure zinc.

[1] If water is added to strong sulphuric acid the acid may spurt, and cause a serious accident.

[2] The mercury used for amalgamating zinc must be kept distinct from that used for experiments on Boyle's law, etc.

Place the amalgamated zinc and a strip of copper in the dilute acid, but do not let them touch. Notice that both metals appear unacted upon. Now make them touch, either in the liquid or outside. Notice that bubbles of gas are evolved, not, however, from the zinc, but from the copper. Instead of bringing the zinc and copper into contact, touch each with one end of a length of copper wire, and again note the evolution of bubbles of gas from the copper.

Remove the zinc and copper strips, wash them, and then carefully dry between blotting paper, and weigh. Replace the strips in the dilute acid, and allow them to remain in contact for fifteen minutes, then again wash, dry, and weigh. It will be found that although bubbles of gas have been continuously evolved from the copper it has not lost weight, while on the other hand the zinc has.

It is evident that here we are dealing with something more than simple chemical action, since it is the formation of a metallic connection between the copper and zinc which apparently causes the evolution of the gas from the copper and the eating away of the zinc. We shall, in fact, find that the wire joining the two metals possesses many distinctive and curious properties, which it did not possess before it was connected to the copper and zinc placed in the acid.

The arrangement consisting of two metal plates, one of zinc and the other of copper, dipping in dilute acid, and connected by a metal wire, constitutes what is called a *voltaic element or couple*. The peculiar properties possessed by the connecting wire are said to be due to the passage of an electric current, this current being, for convenience, supposed to flow through the wire from the copper plate to the zinc plate. The points where the wire is attached to the metal plates are called the poles of the cell, and in order to distinguish the two, the pole from which the current is supposed to flow (copper) is called the positive pole, and the other pole (zinc) is called the negative pole.

EXERCISE 176.—*Effect of current on a suspended magnetic needle.*

Apparatus:—Daniell cell; copper wire: pivoted compass needle.

The simple cell set up in the previous exercise is not suitable for experiments on the electric current, since it is found that the current it sends rapidly diminishes. For many of the following

experiments a form of cell called a Daniell cell will be used. This cell consists of a rod of amalgamated zinc, forming the negative pole, placed in dilute sulphuric acid contained in a pot made of porous earthenware. This porous pot is surrounded by another vessel of glass or glazed earthenware, which is filled with a solution of copper sulphate. A plate of copper dipping in the copper sulphate solution forms the positive pole. Such a cell will send a current for some time without becoming exhausted. It is, however, important, whenever you are not using the current, to disconnect the wires, etc., joining the two poles.

Connect the poles of a Daniell cell by a length of about two yards of cotton-covered copper wire (about No. 22). Hold this wire over and parallel to a magnetic needle, which is either suspended by a thin silk fibre or pivoted on a fine point. Notice that the needle is deflected. Disconnect the wire at one end from the cell, and note that the wire no longer affects the needle. Next hold the wire at right angles to the length of the needle (*i.e.* hold it east and west), and observe whether the needle is deflected when the cell is connected up to the wire.

Fix the wire parallel to the length of the needle, and either just above or just below, and note the direction in which the north pole is deflected. Then reverse the connections of the wire and cell, *i.e.* connect the end of the wire which was connected to the positive to the negative pole, and *vice versâ*. Again, note the direction in which the north pole is deflected.

Action of Current on Magnetic Needle.—The preceding experiments have shown that when a wire through which a current is passing is held near a magnetic needle, the needle tends to set itself at right angles to the wire, and that the direction in which the north pole is urged depends on the

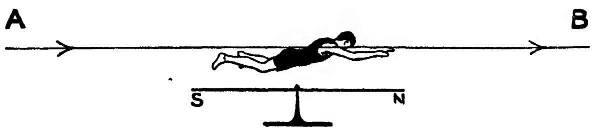

FIG. 109.

direction of the current in the wire. A rule for remembering in which direction the needle will be deflected is as

follows :—Suppose yourself swimming in the wire in the same direction as the current is flowing and facing the north pole of the needle, then this pole will be urged to your left. Thus, if AB (Fig. 109) is a conductor conveying a current in the direction shown by the arrows, and N is the north pole of a magnetic needle, NS; then the north pole will be acted upon by a force tending to drive it down through the page, *i.e.* to the left of a man swimming with the current and facing the needle.

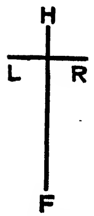

FIG. 110.

EXERCISE 177.—*Deflection of magnet by a conductor conveying a current.*

Apparatus as in Exercise 176.

Fasten to the wire a piece of paper lettered, as in Fig. 110, to represent a man. The lettered side represents the face, L being the left hand, and R the right. Test the truth of the above rule for each of the positions of the current with reference to the needle shown by the arrows in Fig. 111. In each case make a drawing of the arrangement, showing the paper cross in position. Also show that from the rule it follows

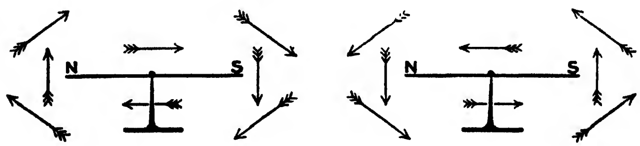

FIG. 111.

that *each* part of a wire bent into a rectangle, or loop, and placed round the needle, will tend to deflect the needle in the same direction. Illustrate your answer by sketches.

EXERCISE 178.—*Lines of force of a wire conveying a current.*

Apparatus :—Two Grove or Bunsen cells; about 2 feet of No. 18 uncovered copper wire; iron filings; small compass.

Connect the negative pole (zinc) of one of the cells supplied to you, and the positive pole of the other cell, and join the ends of a piece of stout copper wire, about 2 feet long, to the other two poles.

Dip this wire in iron filings, and notice how they cling to the

wire. Stop the current by disconnecting the wire at one end from the cells : the filings immediately drop off the wire.

Pass the wire through a hole in a sheet of cardboard, and, holding the cardboard horizontal and the wire vertical, pass the current. Scatter iron filings over the cardboard, and gently tap so as to facilitate the setting of the particles of iron parallel to the lines of force. Make a sketch of the lines of force as shown by the filings. Place a small compass at different points on the card, and notice in which direction the magnetic needle points. Hence determine, and mark on your drawing of the lines of force, the direction in which a north pole would travel. Show by a figure that this result is in accordance with the rule given on p. 208.

EXERCISE 179.—*Heat developed by the electric current.*

Apparatus :—Two Grove or Bunsen cells ; a few inches of very fine platinum wire.

Connect the two cells as in the previous exercise. Twist the ends of a piece of fine platinum wire to two pieces of copper wire, and connect the other ends of these wires to the other poles of the cells. Notice that the platinum wire becomes hot. Gradually shorten the length of platinum wire, and notice how it gets hotter and hotter, and is finally fused. Try to fuse a piece of the platinum wire in a Bunsen flame, and so get an idea of the extremely high temperature which may be developed by the passage of a current.

EXERCISE 180.—*Solenoid.*

Apparatus :—Cotton-covered wire (No. 20) ; piece of glass tube ; Daniell cell ; compass : iron and steel rods to fit inside tube.

On a piece of glass tube, about 7 inches long and $\frac{1}{2}$ inch in diameter, carefully wind a single uniform layer of cotton-covered copper wire, fastening the ends with a little sealing-wax, so that the wire will not come uncoiled. Connect the ends of the wire forming the coil to the poles of a Daniell cell, and bring first one end of the coil, then the other, near a pivoted or suspended magnetic needle, and carefully note what happens. In what respects does this coil of wire (called a solenoid), when traversed by an electric current, behave like a magnet? Reverse the current by interchanging the battery connections, and note that the polarity of the coil is also changed. Facing that end of the coil which behaves like a north pole, in which direction is the current circulating in the coil?

Place an iron rod inside the coil, and notice that it become

strongly magnetized, and will attract iron and steel bodies. Does the end of the iron next the end of the coil which behaves like a north pole, become a north or a south pole? Replace the iron by a rod of steel, and notice that the steel becomes magnetized, and retains its magnetism after the current has been stopped.

EXERCISE 181.—*Solenoid (continued).*

Apparatus:—Cotton-covered copper wire: concentric mercury cups; Daniell cell.

Wind about thirty turns of covered copper wire on a pencil, or use the coil made in the last exercise, bringing the free ends of the wire back to the middle, and fastening them there with a few turns of cotton or with sealing-wax, in the manner shown at AB, Fig. 112. Cut off the ends of the wire, leaving about 2 inches projecting, and from the ends remove the cotton covering. Amalgamate these ends by dipping them into some nitric acid, and then into mercury. Suspend the coil by a double loop, and a single thread of unspun silk about 18 inches long, so that the ends of the wire dip one in each of two concentric mercury cups, as shown in the figure. The construction of these mercury cups is shown in section in Fig. 113. The wire C passes through the wood to the inner mercury cup, while the wire D dips in the outer cup. If, then, C is connected to the positive pole of a Daniell cell, and D to the negative pole, the current will come in at C, and thence pass up the wire A, through the coil, and out by the wire B, the mercury in the outer cup, and the wire D.

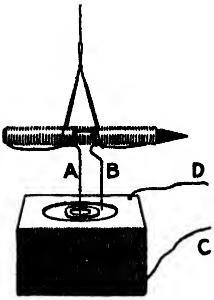

FIG. 112. (½.)

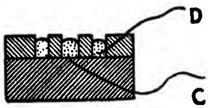

FIG. 113. (½.)

Bend the wires A and B, till the coil will turn freely without the ends of the wires touching the sides of the mercury cups, and then connect the wires C and D with the poles of a Daniell cell. It will be found that, on the passage of the current, the suspended coil sets itself with its axis in the magnetic meridian just as a suspended magnet would do. Bring the pole of a magnet near the coil, and notice how one end is attracted and the other repelled; and determine, as in the previous exercise, in

which direction the current is circulating when you face towards the north-pointing end of the coil.

The Galvanometer.—It has been seen, in Exercise 177, that if a wire through which a current is passing forms a loop surrounding a suspended or pivoted magnetic needle, then each part of this loop tends to deflect the needle in the same direction. If, now, instead of the wire forming a single loop, there are a number of loops, then the current in each of these loops will tend to deflect the needle, so that a much larger deflection will be obtained than when a single loop is used. The above is the principle of the galvanometer, which is an instrument for detecting, and, in some forms of galvanometer, measuring electric currents. It consists essentially of a number of turns of insulated wire (the coil) surrounding a suspended or pivoted magnetized needle. The ends of the wire forming the coil are brought to two metal terminals, or binding-screws. In order to use the galvanometer to detect whether a current is passing in any circuit, the circuit is broken at some point, and the two ends joined to the two binding-screws of the galvanometer, then if the needle is deflected, it shows that the galvanometer, and therefore the circuit of which it now forms a part, is traversed by a current.

EXERCISE 182.—*The Galvanometer.*

Apparatus :—Galvanometer ; Daniell cell.

A form of galvanometer described by Professor Balfour Stewart, and suited for use in these exercises, is shown in Fig. 114. It consists of a wooden ring, AB, on which about thirty turns of silk-covered copper wire are wound. The ends of the wire are fastened to the two terminals, C and D. The wooden ring is attached to a platform, E, on which a compass-box slides. The compass-box contains a magnetized needle, *ns*, supported on a pivot, and having a light aluminium pointer, GH, attached. This pointer moves just above the surface of a card graduated in degrees, and when the pointer is at the zero division the needle is parallel to the coils of wire. The compass-box can be placed at different distances from the coil, so that the sensitiveness of the instrument can be altered. The reason

for having the pointer GH at right angles to the needle is, that, in order to read the position on the scale without any error due to parallax (p. 5), the eye must be placed exactly vertically over the

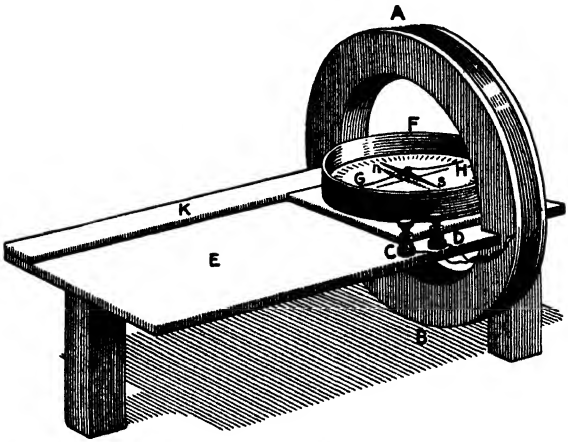

FIG. 114. ($\frac{1}{5}$.)

end of the pointer. If the pointer were parallel to the needle, or it the positions of the ends of the needle itself were read, then, for small deflections, the coil AB would prevent the eye being placed vertically over the pointer.

Place the galvanometer so that the pointer is at the zero of the scale, and therefore the coil in the magnetic meridian. Connect the terminal D with the positive pole (copper) of a Daniell cell, and touch the other terminal with a wire connected with the other pole of the cell. Notice the amount and the direction in which the needle is deflected. Reverse the battery connections, and again note the direction and amount of the deflection. Move the compass-box further and further away from the coil, and note the deflection in each case.

Set the coil of the galvanometer east and west, and again connect the terminals with the poles of the cell. Why is it that you now obtain little or no deflection, although the current is passing through the coil? This experiment shows the necessity of placing the coil of the galvanometer in the magnetic meridian, when it is used to detect the passage of a current.

EXERCISE 183.—*Electrical resistance.*

Apparatus:—Galvanometer; Daniell's cell; wires of various diameters and materials.

Connect one terminal of the galvanometer to one pole of a Daniell cell by a length of copper wire, and connect the other terminal to the other pole by a long length (about 4 feet) of thin copper or brass wire. Move the compass-box away from the coil till a deflection of 10° to 20° is obtained, then read the deflection. Next reduce the length of the thin wire to about half, and again note the deflection. It will be found to have increased. Also take the deflections on the galvanometer when connected up by two wires of the same length, but of different diameters. Notice that the deflection obtained with the thick wire is greater than with the thin.

Repeat the experiment, using two wires of the same length and diameter, but one of copper and the other of German-silver. Notice that the deflection obtained with the copper wire is the greater.

Resistance.—The experiments made in the preceding exercises show that the current which a given cell can send through a wire depends on its length, its diameter, and the material of which it is composed. It is also evident that the longer and thinner is the wire the smaller is the current which the cell can send through it; so that the wire seems to offer a *resistance* to the passage of the current. This resistance of a wire to the passage of an electric current increases with the length of the wire and decreases as the wire is made thicker. Two wires of the same length and thickness, but made of different materials, have, however, different resistances. The current which the cell in the last exercise sent through the circuit depended on the total resistance in circuit, consisting of the resistance of the two wires connecting the cell to the galvanometer, the resistance of the wire of the galvanometer coil, and the resistance of the liquid joining the copper and zinc plates of the cell.

EXERCISE 184.—*Battery resistance.*

Apparatus:—Galvanometer; plates of zinc and copper; beaker; sulphuric acid.

Connect the plates of zinc and of copper used in Exercise 175 to

the terminals of the galvanometer. Dip the plates in some dilute sulphuric acid, keeping them as far apart as possible, and, having adjusted the position of the compass-box till a deflection of about thirty degrees is obtained, note the galvanometer deflection. Then move the plates nearer together, but not so as to touch, and notice that the deflection of the galvanometer increases, showing that a larger current is now flowing through the circuit. Thus the decrease in the distance between the plates, and therefore of the resistance which the liquid opposes to the flow of the current, increases the current in the circuit.

Keeping the plates at a constant distance apart, it will be noticed that the galvanometer deflection gradually decreases. This is the phenomenon, referred to on p. 207, which makes such a simple cell unsuited to most experiments where a current is required.

Difference of Potential or Electro-Motive Force.—The experiments made in hydrostatics have shown that, if two vessels containing liquid are connected by a pipe, then the liquid will flow from the vessel in which the liquid stands at a higher level into that at the lower level. Here a difference in level, or a head of liquid, produces a current of liquid in the pipe, this current flowing from the higher level to the lower. This hydrostatic example will assist in making clear what happens when the two poles of a cell are connected by a wire. It must, however, be clearly understood, that the electric current is *not* a flow of some body called electricity through the wire. We may, however, think of the two poles of a cell as being at different electrical "levels," so that when they are connected by a wire there is a flow of electricity through the wire from the pole at the higher level to that at the lower, this flow constituting the electric current. In the case of electricity the difference in level between two points is called the *difference of potential*, or the *electro-motive force* between the two points. The point from which the current is supposed to flow being at the higher potential.

If we connect the terminals of a galvanometer to two points in a circuit, then if these points are at different potentials a current will flow through the galvanometer and the needle be

deflected; and by observing the direction in which the needle is deflected we can determine which of the points is at the higher potential. If, however, the galvanometer is undeflected it shows that the two points are at the same potential, since when they are joined by a wire (the wire of the galvanometer coil) no current passes in this wire. In the subsequent exercises we shall often make use of a galvanometer in this way, to test whether two points on a circuit are at the same potential.

EXERCISE 185.—*Fall of potential along a wire conveying a current.*

Apparatus:—Galvanometer; Daniell cell; wire.

Connect the ends of a piece of copper wire (No. 22 uncovered), about two metres long, to the poles of a Daniell cell, and stretch the wire out on the table over four pins fixed into the table, as at ACDE, Fig. 115. Join one terminal of the galvanometer to the

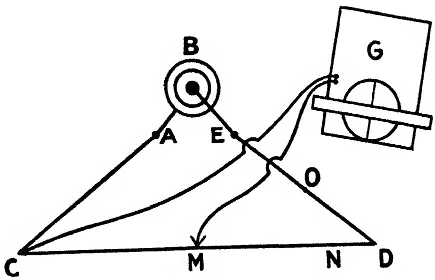

FIG. 115.

wire at C, and, with the end of a wire attached to the other terminal, touch the stretched wire also at C. Notice that there is no deflection. The two terminals of the galvanometer touch the circuit at the same point, and therefore there is no difference of potential between the points of contact.

Next, keeping one terminal at C, touch the stretched wire at some other point, M, between C and the negative pole (zinc) of the battery. Note the amount and direction of the deflection. Which of the points C or M is at the higher potential?

Move the contact to N and O, and note that the deflection is in the same direction, but that it increases as the contact is made further away from C. To what conclusion does this lead as to the magnitude of the differences of potential between C and M, C and N, and C and O? In this connection, remember that, in the hydrostatic illustration given on p. 214, the greater the head of water the greater the flow of the water in the pipe.

Now connect the second terminal of the galvanometer to the stretched wire at A, keeping the other terminal still at C. From the direction of the deflection obtained decide which of the points, C or A, is at the higher potential.

Disconnect the cell first at the negative pole, then at the positive pole, and in each case test for a difference of potential between different parts of the stretched wire. No current will now be flowing through the stretched wire, it is only when a current is flowing that different parts of the wire are at different potentials.

EXERCISE 186.—*Fall of potential along a wire conveying a current.*

Apparatus as in previous exercise.

Take three pieces of wire of the same length (about a foot), one of thick copper, another of thin copper, and the third of the same diameter as the thin copper, but of German-silver. Twist the ends of these wires together, and to two lengths of copper wire connected to the poles of a Daniell cell, as shown in Fig. 116, where AC is

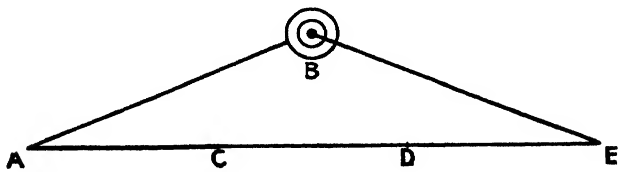

FIG 116.

the thick copper wire, CD the thin, and DE the German-silver wire.

Find the deflection on the galvanometer when its terminals are connected by the same pair of wires, first with A and C, then with C and D, and lastly with D and E. From the deflections obtained to what conclusions are you led as to the magnitude of the differences

of potential between A and C, C and D, and D and E? What are the relative resistances of AC, CD, and DE, as found in Exercise 183? Do you see any connection between the resistances of the wires and the difference of potential between the ends, when, as in this experiment, the same current flows through all the wires?

EXERCISE 187.—*Fall of potential along a wire conveying a current.*

Apparatus as in previous exercise.

Take three equal lengths of the same-sized uncovered copper wire (No. 22 or 24) and connect them as shown at AB, BCD, and BNOD, in Fig. 117. Connect A and D with the poles of a Daniell cell. Then the current which flows through AB on reaching B divides, and half goes through BCD, the other half through BND. Thus the current in AB is twice as strong as in BND.

Measure off a length AM of AB, and an equal length NO of BND, and observe the galvanometer deflections when the terminals

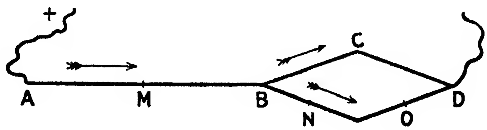

FIG. 117.

are connected first to A and M, and secondly to N and O. Is the difference of potential between A and M greater or less than between N and O? The resistance of AM is equal to the resistance of NO since they are exactly similar pieces of wire, being of the same length, diameter, and material. The current flowing through AM is, however, greater than the current flowing through NO. How does the difference of potential between the ends of a wire vary when the current is increased?

Ohm's Law.—We have seen that, when a current passes through a wire, there is some connection between the current flowing, the resistance of the wire, and the difference of potential between the ends of the wire. The true expression for the connection between these three quantities was first given by

G. S. Ohm in 1827. Ohm showed from theoretical considerations, and subsequent experiments carried out by others have confirmed his view, that the ratio of the difference of potential between the ends of any given conductor to the current passing is a constant, no matter how great the current, so long as the temperature of the conductor is not altered. This constant ratio of the difference of potential to the current is what we have called the resistance of the conductor. The above law is known as Ohm's Law, and it affirms that the resistance of a conductor does not depend on the value of the current passing in the conductor, but is an independent physical property of the conductor, just as much as its mass or volume.

It follows from Ohm's law, that if the same current passes through two conductors, then the differences of potential between their ends are to one another as their resistances. For let C be the current, E_1 the difference of potential between the ends of the first conductor, and R_1 its resistance; E_2 and R_2 being the corresponding quantities for the other conductor: then, by Ohm's law,—

$$R_1 = \frac{E_1}{C} \text{ and } R_2 = \frac{E_2}{C}$$

$$\text{or } C = \frac{E_1}{R_1} = \frac{E_2}{R_2}$$

$$\text{or } \frac{E_1}{E_2} = \frac{R_1}{R_2}$$

EXERCISE 188.—*Comparison of resistances.* (*Wheatstone's net.*)

Apparatus:—Galvanometer; Daniell cell; German-silver wire.

Stretch a length of about three feet of German-silver wire between two pins, CD (Fig. 118), fixed into the table, and connect C and D to the poles of a Daniell cell, B. Fasten together at F the ends of the two wires whose resistances have to be compared, and fasten the other ends to C and D. Also join one terminal of the galvanometer to F. With the end of a piece of copper joined to a wire connected to the other terminal of the galvanometer, touch different parts of the stretched wire CD till a point, E, is found where, on

making contact, no deflection is produced. Since there is no deflection it follows that the points E and F are at the same

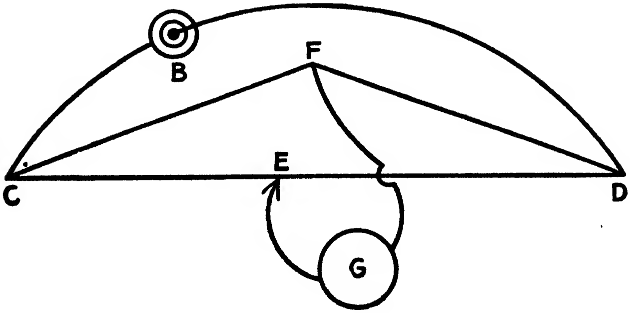

FIG. 118.

potential. Therefore the difference of potential between C and E is equal to the difference of potential between C and F, and the difference of potential between E and D is equal to that between F and D. Hence,—

$$\frac{\text{Difference of potential between C and E}}{\text{Difference of potential between E and D}}$$
$$= \frac{\text{difference of potential between C and F}}{\text{difference of potential between F and D}}$$

But since no current passes through the galvanometer, the current in CE must be equal to the current in ED, and the current in CF equal to the current in FD. Therefore, from what has been said on p. 218,—

$$\frac{\text{Resistance of CE}}{\text{Resistance of ED}} = \frac{\text{difference of potential between C and E}}{\text{difference of potential between E and D}}$$

Also—

$$\frac{\text{Resistance of CF}}{\text{Resistance of FD}} = \frac{\text{difference of potential between C and F}}{\text{difference of potential between F and D}}$$

Therefore—

$$\frac{\text{Resistance of CE}}{\text{Resistance of ED}} = \frac{\text{resistance of CF}}{\text{resistance of FD}}$$

Since CD is a uniform wire—,

$$\frac{\text{Resistance of CE}}{\text{Resistance of ED}} = \frac{\text{length CE}}{\text{length ED}}$$

So that finally—

$$\frac{\text{Resistance of CF}}{\text{Resistance of FD}} = \frac{\text{length CE}}{\text{length ED}}$$

Thus, by measuring the lengths CE and ED of the stretched wire, we can obtain the ratio of the resistances of the wires CF and FD.

Measure by this method the ratio of the resistance of each of the wires supplied to you to that of the copper wire. Also taking the resistance of a metre of the copper wire as the unit, calculate the resistance of a metre of each of the other wires.

Wheatstone's Bridge.—In order to apply the method of comparing two resistances given in Exercise 188, it is convenient to make use of an instrument called a Wheatstone's bridge, in which the wire along which the movable contact can be displaced is stretched over a divided scale. A simple form of Wheatstone's bridge,[1] which is capable of giving very fairly accurate results, is shown in Fig. 119. In this figure

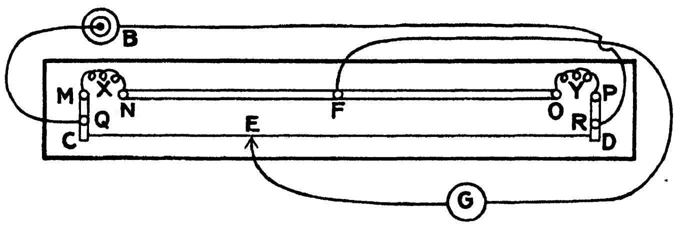

FIG. 119.

CM, NO, and PD are three strips of thick copper, and CD is the stretched wire. At Q, M, N, F, O, P, and R, binding screws are soldered on to the copper strips, while the ends of the wire are soldered to the strips CM and DP. The poles of the battery are connected to two binding screws,

[1] Particulars of the dimensions, etc., of this bridge will be found in the Syllabus of the Course in Physics at the Royal College of Science, South Kensington. (Eyre and Spottiswoode.)

Q and R, while one terminal of the galvanometer is connected to F and the other is connected to a length of wire which is soldered to a small piece of copper with which contact can be made with any part of the stretched wire. The copper strips CM, NO, and PD, are so thick and wide that they practically have no resistance. If the resistances to be compared are placed one connecting M and N, and the other connecting O and P, then the resistances of the copper strip between Q and M and between N and F, etc., can be neglected.

Suppose that when there is a resistance X between M and N, and a resistance Y between O and P, that in order to obtain no deflection of the galvanometer the contact has to be made at E. Then, as can be easily seen by comparing Fig. 119 with Fig. 118, where the parts are similarly lettered—

$$\frac{X}{Y} = \frac{\text{length CE}}{\text{length ED}}$$

The lengths CE and ED are read off directly from the divided scale which is fixed alongside the wire, and in which the graduations are numbered starting both from C and from D.

EXERCISE 189.—*Wheatstone's bridge.*

Apparatus:—Wheatstone's bridge; Daniell cell; galvanometer; uncovered German-silver wire;[1] metre scale.

Divide the German-silver wire supplied to you into two portions, one of which is about twice as long as the other. Insert one of these pieces of wire in each of the gaps MN and OP (Fig. 119) of the Wheatstone's bridge. Connect the terminals of the battery to the binding screws Q and R, and connect one terminal of the galvanometer with F. Adjust the galvanometer so that the coil is parallel to the magnetic meridian, and the compass box is as near the coil as possible. Then, with a piece of copper soldered to a wire connected to the other galvanometer terminal, find the position on the stretched wire at which contact produces no deflection of the galvanometer. Take the readings on the scale giving the lengths of the two segments into which the stretched wire is divided when balance is obtained.

[1] Fine brass or steel wire will do almost as well as the German-silver.

Bend the ends of the wires at right angles where they leave the binding screws, so as to obtain the exact length of wire of which the resistance has been measured. Interchange the wires, being careful to clamp them in the binding screws just up to the bend, and again find the position of balance. If the bridge is well made, the ratio of the segments into which the stretched wire is now divided, ought to be the same as before. If there is only a small difference between the two ratios the mean may be taken as giving the correct ratio of the resistances of the two wires.

Measure the lengths of the two wires and show that the resistances are to one another as the lengths.

Connect the terminals of the galvanometer to the binding screws Q and R (Fig. 119), and one pole of the cell to F. With a piece of copper soldered to a wire connected to the other pole of the cell make contact at different points on the stretched wire till a position is found such that on making contact no deflection of the galvanometer is produced. Notice that the point at which balance is now obtained is the same as that found before the position of the cell and galvanometer had been interchanged. It will generally be found better to employ this arrangement of the battery and galvanometer rather than that in which the movable contact is attached to the galvanometer.

EXERCISE 190.—*Resistance of wires.*

Apparatus as in previous exercise.

Insert two wires of the same material, but of different sectiona areas, in the two gaps of the bridge. Find the point of balance, and hence get the ratio of the resistances. Interchange the wires, again balance, and take the mean of the two values obtained for the ratio of the resistances.

Obtain the area of cross-section of the wires by measuring the diameter with a screw gauge and calculating the area by means of the expression—

$$\text{Area} = \pi r^2, \text{ where } r \text{ is the radius.}$$

Show that the resistances of the wires are to one another inversely as the sectional areas. That is, show that $\frac{R_1}{R_2} = \frac{\pi r_2^2}{\pi r_1^2}$ where R_1 and r_1 are the resistance and radius of the one wire, and R_2 and r_2 are to be corresponding quantities for the other wire.

Repeat the experiment several times, using different lengths of wire.

Specific Resistance.—It has been found in the previous exercises that the resistance of a wire is directly proportional to its length and inversely proportional to its sectional area. Two wires of the same length and sectional area, but one made say of copper and the other of German-silver, have not, however, the same resistance.

The resistance of a wire of any material of unit length and having a cross-section of unit area, is called the *specific resistance* of the material. Thus, if k is the specific resistance of a material, then the resistance of a wire of which the length is l and the area of cross section is a, will be—

$$\frac{lk}{a}$$

EXERCISE 191.—*Comparison of the specific resistance of two wires.*

Apparatus as in previous exercise, with the addition of wires of copper, brass, and iron.

Place a copper wire in one arm of the bridge, and a German-silver one in the other and compare their resistance as in the previous exercise. Measure the length and diameter of each wire.

Let R_1, l_1, r_1, and k_1, be the resistance, length, radius, and specific resistance of one wire, and R_2, l_2, r_2, and k_2, the corresponding quantities for the other, then—

$$R_1 = \frac{l_1 k_1}{\pi r_1^2} \text{ and } R_2 = \frac{l_2 k_2}{\pi r_2^2}$$

$$\therefore k_1 = \frac{\pi r_1^2 R_1}{l_1} \text{ and } k_2 = \frac{\pi r_2^2 R_2}{l_2}$$

$$\therefore \frac{k_1}{k_2} = \frac{r_1^2}{r_2^2} \cdot \frac{l_2}{l_1} \cdot \frac{R_1}{R_2}$$

All the quantities on the right hand side of this equation are known for r_1 and r_2, are obtained from the diameters, l_1 and l_2 have been measured, and the ratio $\frac{R_1}{R_2}$ is given by the measurement with the Wheatstone's bridge. Calculate in this way the ratio of the specific resistance of German-silver to that of copper.

Repeat the experiment, using copper and brass wire.

EXERCISE 192.—*Effect of an increase of temperature on the resistance of a wire.*

Apparatus as in previous exercise.

Place a piece of copper wire in each of the gaps of the bridge and find the point of balance. Heat one of the wires by means of a Bunsen flame, and notice in which direction the galvanometer needle is deflected, or in which direction the point of contact on the wire has to be moved in order to restore the balance. Try in which direction the needle is deflected, or the point of contact for balance moved, when one of the wires is slightly shortened. Hence find whether heating a copper wire increases or decreases the resistance.

Repeat the experiment, using brass, iron, and German-silver, and note any difference in the magnitude of the change in resistance produced by heating in the different cases.

EXERCISE 193.—*Resistance of two conductors in parallel.*

Apparatus as in previous exercise.

Take three lengths of German-silver wire, each about two feet long. Place one of these in one of the gaps of the bridge, and using this wire as a standard, compare with it the resistance of each of the others. Taking the resistance of this standard piece of wire as unity let the resistance of the other pieces be R_1 and R_2.

Next, keeping the standard wire in the one gap, place the other two pieces in the other gap end to end or in series, as it is called, and compare their resistance with that of the standard. Hence show that the resistance of the two wires in series is $R_1 + R_2$.

Next place the two wires in the gap so that they stretch side by side from one binding screw to the other. The wires are now said to be in parallel. Compare their resistance when in parallel (R_3) with the standard, and show that $\frac{1}{R_3} = \frac{1}{R_1} + \frac{1}{R_2}$.

APPENDIX I.

To Solder Metal Objects.—Obtain a tinman's $\frac{3}{4}$-lb. copper soldering-bit and heat it very nearly to redness. As quickly as possible file the end bright, and dip for an instant into a solution of zinc chloride, which may be prepared by dissolving scrap zinc in hydrochloric acid. Then rub the clean part of the soldering-iron on a small piece of tinned iron on which a little solder has been placed. In this way the soldering-iron will become coated with a bright layer of solder. In subsequent heating, care must be taken not to heat the bit to such a temperature that this coating of solder is burnt off. If this happens the bit must be filed bright, and again coated with solder.

Clean the surfaces of the pieces of metal which are to be soldered by scraping, filing, or rubbing with emery-cloth till they are quite bright. It is absolutely essential, if a good joint is to be obtained, that every speck of tarnish should be removed. Moisten the cleaned surfaces with zinc chloride solution and then pass the hot soldering-bit, *having previously dipped it into the zinc chloride solution*, over the cleaned surfaces. In this way these surfaces will be covered with a thin continuous coating of solder, this operation is called tinning the work. Again moisten the surfaces with zinc chloride, and fix them together in the position they are to occupy, either by holding them with a pair of pliers or by binding them together with fine wire. Then either heat the pieces of metal over a Bunsen flame, or hold the hot soldering-bit against them. If there does not appear to be enough solder, a *small* fragment of solder may be placed at the junction of the two surfaces. This solder will immediately be sucked into the joint. It is important to remember that the smaller the quantity of solder used, provided there is enough to make a continuous layer of solder between the surfaces, the stronger will be the joint. If the solder does not readily flow into the joint, draw a piece of wood

which has been dipped in zinc chloride round the edge of the joint. After the joint is complete it must be thoroughly washed with *hot* water to remove the zinc chloride, which will otherwise corrode the metal. This washing with hot water (if it is possible it is better to actually boil the article) is particularly necessary when electrical junctions are being made. If the nature of the work is such that the washing cannot be performed, powdered rosin must be used as a flux in place of zinc chloride. If the metal surfaces are well cleaned and the soldering-iron is hot and clean, it will be found almost as easy to obtain satisfactory joints with rosin as with zinc chloride.

To Silver Glass.—Make up the two following solutions, being particularly careful as to cleanliness.

1. Dissolve 5 grms. of crystallized silver nitrate in about 200 c.c. of distilled water. Pour about 50 c.c. of this solution into a second beaker, and add ammonia (solution) to the bulk of the solution till the precipitate first thrown down is *almost* entirely redissolved. It will be found that the precipitate seems to disappear suddenly, at the end, and the object of keeping 50 c.c. of the solution was to allow for an accidental addition of too much ammonia. The 50 c.c. must be added to the rest after the process of precipitation and solution with ammonia has been performed on it also. Filter the solution, and add enough distilled water to make the solution up to 500 c.c.

2. Dissolve 1 grm. of silver nitrate in a little distilled water, and pour into 500 c.c. of boiling distilled water. Add 0·8 grm. of Rochelle salt (potassic sodic tartrate), and allow the mixture to boil till the precipitate contained in the solution becomes grey, then filter while still hot.

These two solutions must be kept in well-stoppered bottles *in the dark*.

The glass surface to be silvered must be cleaned by washing with (1) nitric acid, (2) water, (3) caustic potash, (4) water. Then a solution of stannous chloride (proto-chloride of tin) must be run over the surface which is to be coated only, and the whole well washed first with tap water, then with distilled water. While still wet the glass is placed in a clean glass or porcelain vessel, with the surface which is to be silvered uppermost, and equal volumes of the two solutions are mixed in a beaker (not one which has been used for stannous chloride solution) and then quickly poured into the vessel so as to cover the glass with about one inch of solution. Allow to stand for about an hour, when the silvering will be

complete. If the solutions are heated to 30° C. the silver will be deposited in about ten minutes, but the coating will not be so firm and uniform as if the solutions are used cold. Pour off the solution and wash the glass, rubbing the silver off any parts where it is not required. Allow the silver to dry, and then give it a coating of some varnish, such as golden lacquer, which does not contract much on drying. The silvered surface must not be touched till it is quite dry, or it will become stained and scratched.

To Bend Glass Tube.—Glass tube is best bent in an ordinary bat's-wing gas flame; it is very difficult to get a regular bend in a Bunsen flame or with a blow-pipe flame. Hold the tube horizontal, supporting it on both sides of the point where it is being heated in your hands, holding *both* hands with the knuckles turned upwards. Keep the tube slowly rotating till it becomes quite softened. It is better to heat too much rather than too little. Remove the tube from the flame, then with a slow and steady motion turn the two ends of the tube *downwards* till the bend is complete. With tube up to ⅜ in. in diameter the bend ought to be completed at one operation; with wider tube it will be necessary to do part of the bend, then heat the tube a little further along, completing the bend at three or four operations.

To Draw Out a Tube.—Heat the tube in a rather wide blow-pipe flame, supporting the two ends between the ball of the thumb and the points of the first three fingers of each hand, both knuckles being held either facing upwards or downwards. Keep the tube rotating backwards and forwards by rolling it over the fingers by means of the thumbs, being particularly careful to turn the two halves at the same rate. While the glass is in the flame do not pull the ends apart, but let the diameter of the glass become slightly contracted by the glass thickening. Remove the glass from the flame, and then draw the two ends apart. If the tube has only to be slightly reduced in diameter, draw the ends apart very slowly; if a capillary is required, draw the ends apart quickly.

To Seal the End of a Glass Tube.—1. Cut the end off square, and then, keeping the tube in continuous rotation, heat the extreme end at the *edge* of a blow-pipe flame till the sides fall together and close up the end. If a thick lump of glass is formed at the end, this may be removed by heating in the flame, and, while it is still in the flame, pulling the lump off with a piece of cold glass. Then heat the end of the tube, and, after removing it from the flame, gently blow into the open end.

2. Another method which may be adopted is to draw off the

tube as if making a capillary, then holding the part of the tube where the capillary commences in a rather pointed flame and again drawing off. The small bead of glass left at the end of the closed tube can be removed as in the previous method by touching with a piece of cold glass, and finally gently blowing down the tube.

To Blow a Bulb on the End of a Piece of Glass Tubing.—Seal the end of the tube, then, holding it, with the open end a little lower than the closed end, between the ball of the thumb and the face of the fingers of the right hand, the knuckles being turned downwards, heat the tube near the closed end, but not quite at the end, in the blow-pipe flame. Keep the tube turning to and fro by rolling it over the fingers by means of the thumb. The rotation must be so timed as to counteract the tendency of the soft glass to bend at right angles to the rest of the tube. If there appears any likelihood of the sides collapsing and closing the bore, remove the tube from the flame and *gently* blow into the open end. It will be found that in this way the glass can be collected at the closed end, but that this thickened mass of glass is still hollow, the bore of the tube being continued nearly up to the end. When sufficient glass has been collected in this way, heat it up well, then remove from the flame, and, holding the tube nearly vertical, with the closed end downwards, blow *gently and steadily* into the open end till a bulb of the required size is obtained.

If the bulb is unsatisfactory, the glass must again be collected into a small pear-shaped hollow mass, and the process of blowing repeated. While reducing a bulb in this way, if it shows an inclination to become wrinkled, gently blow a small puff of air into the tube. When blowing bulbs it is of use to remember that, if you blow immediately after you take the glass out of the flame, the thin parts will get thinner. If, however, you wait a moment before blowing, then the thin parts will have cooled more than the thick parts, so that now the thick parts will be most blown out and thus will become thinner.

APPENDIX II.

Apparatus and Materials.—In addition to the fittings of the laboratory, such as tables, gas and water connections, sinks, etc., there will be required a certain amount of apparatus and material. The following lists of materials and apparatus are given in order to assist those who are fitting up a laboratory for elementary practical physics. List A contains those materials of which a stock ought to be kept, and which will require renewing from time to time as the stock gets exhausted. List B contains the apparatus required for the exercises, which will have to be bought from an instrument maker. List C contains directions for making such of the apparatus as has either not been described in detail in the text, or the construction of which is not obvious from the figures. All the apparatus in this list may well be made in the workshop of the school itself.

A.

General Stores.

Beakers (various sizes).
Bristles (hog's).
Brushes.
Copper (thin sheet).
Corks (various sizes).
Cotton and thread.
Cotton-wool.
Emery cloth.
Flasks.
Funnels.
Iron filings.
Leather.
Lycopodium.
Mercury.
Methylated spirit.
Paraffin oil.
Paraffin wax.
Pins (ordinary and blanket).
Rosin.
Rubber tubing.
Salt.
Sand-paper.
Shellac.
Shot.
Silk: (1) cocoon fibre.
  „ (2) unspun.
  „ (3) ribbon $\frac{1}{8}$ in. wide.
Soft red wax.
Straws.
Tinfoil.
Turpentine.
Watch glasses.
Wire gauze (iron).
Zinc (thin sheet).

Nitric acid, Sulphuric acid, Copper sulphate } commercial.	Strontium chloride.
Calcium chloride (crystallized).	Lithium chloride.
Magnesium chloride.	Thallium chloride.
	Ether.

Wire.—Steel and brass piano wire, Nos. 24 and 28 S.W.G. (standard wire gauge).

Uncovered copper wire, Nos. 20 and 30 S.W.G.

Uncovered German-silver wire, No. 28 or 30 S.W.G.

Cotton-covered copper wire, Nos. 20 and 24 S.W.G.

Glass tube (soft soda). The most useful sizes are of the following outside diameters : 1, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{3}{8}$, $\frac{5}{16}$, and $\frac{3}{16}$ in.

Thermometer tube, bore $\frac{1}{32}$ in.

Curve paper.—Paper divided in millimetre squares is made by Schleicher and Schüll (agent : Bemrose and Sons, 23, Old Bailey, E.C.). The paper is supplied in two forms, (*a*) in sheets 18 in. by 23 in., at 5*s.* 6*d.* for 24 sheets (No. 113) ; or (*b*) in a continuous roll, 30 in. by 11 yards, at 12*s.* (No. 106). The single sheets are thus a little cheaper than the roll, but may involve a little more waste in cutting up. If the curve paper is always supplied to the student cut to the size he will require for the experiment, much waste will be avoided.

B.

In the following list the number of each instrument required for a class of twelve students is given. With larger classes it will not be necessary to duplicate some of the instruments, such as screw-gauge, calipers, Hope's apparatus, metronome, etc. For the information of those who have any difficulty in obtaining the apparatus, the name of the maker or agent from which the instruments described in the text have been obtained are given. It must be understood that in nearly every case suitable apparatus can be obtained from many other makers, but the ones given are those with whose instruments the author happens to be personally acquainted.

	£	*s.*	*d.*
4 Balances @ £1 14*s.* 6*d.*[1]	6	18	0
(Becker & Co., Hatton Wall, London, E.C. Balance No. 93 to carry 250 grms. If without drawer, 2/6 less.)			

[1] Although cheaper balances can be obtained, this balance is strongly recommended, as it may also be used for the quantitative chemical work of the school.

	£	s.	d.
4 Boxes of weights 200 to 0·01 grm., with forceps, @ 7/6 (Becker.)	1	10	0
1 Set gramme weights 1 to 1000 grms. (Becker, No. 113)	0	5	6
1 Rough scales to carry one kilo (Becker, No. 97) ..	0	17	0
1 Set British weights ¼ oz. to 1 lb.	0	1	6
6 Boxwood metre scales divided in mm. } 6 Boxwood yard scales divided in $\frac{1}{10}$ in. } .. .. (Rabone & Sons, Hockley Abbey Works, Whitmore Street, Birmingham.)	0	12	0
6 Thermometers − 5° C. to + 105° C., divided in half-degrees .. .. (Müller, 148, High Holborn, London, W.C.)	0	12	0
1 Screw gauge .. .. (This is a rather smaller form than the one shown in Fig. 9, and is made by Louis Müller; agent: Becker.)	0	6	6
1 Slide calipers .. .. (Chesterman, Sheffield, No. 1400.)	0	6	0
2 Burettes 50 cc. in $\frac{1}{10}$ cc.	0	8	0
2 Graduated cylinders, one in metric and the other in British units	0	6	0
1 Hydrometer	0	2	6
6 Tuning forks (Becker)	0	6	0
2 Glass letter weights[1]	0	2	0
1 Glass prism, angle about 30°	0	3	0
1 Dense glass prism, angle about 60°	0	10	0
1 Hope's apparatus	0	7	6
1 Bar and gauge for expansion	0	5	0
2 Copper calorimeters	0	5	0
1 Metronome	0	8	0
3 Daniell cells	0	8	0
3 Magnetic needles, 2 in. long, with agate centres .. (Harvey & Peak, 56, Charing Cross Road, London, W.C.)	0	4	6
3 Retort stands and clips	1	0	0
4 Cast-iron weights, either 5 and 10 kilos, or 14 and 28 lbs.	0	15	0
	£16	19	0

Drawing instruments, such as compasses, dividers, and set squares.

[1] These letter weights are about 4½ ins. × 2½ ins. × ¾ in., and may be obtained from most stationers or from Becker.

C.

The construction of much of the apparatus can be made out from the description in the text and the figures. The figures of apparatus are in all cases drawn to scale, and the fraction in brackets after the number of the figure indicates the scale employed. The numbers before each of the following descriptions refer to the exercise in which the piece of apparatus described is employed.

31. Specific gravity flask.—Take a 3-oz. flask with a narrow neck and paste a strip of paper about $\frac{1}{2}$ in. wide round the neck. Then, using the edge of this paper as a guide, make a ring in the glass with a *wire* file, such as is used for fretwork and carving.

32. U-tube.—Each limb should be about 24 in. long; bore of tube about $\frac{1}{3}$ in. The tube is best bent over a large bat's-wing burner, making the bend a little at a time. The clips to fasten the tube to the stand may be made from thin sheet brass.

35. Hare's apparatus.—Tubes each about 28 in. long, and $\frac{1}{4}$ in. bore. The rubber joints connecting the upright tubes with the T-piece must be fastened round with wire. The T-piece may be of metal or of glass.

36. The solid cylinder may be made of wood, weighted with lead, a suitable size being 2 in. long and $1\frac{1}{4}$ in. in diameter. The hollow cylinder may be made by pasting a strip of paper about $\frac{1}{2}$ in. wider than the length of the solid cylinder round this cylinder, and, when this is dry, filling in the end with plaster of Paris. After the removal of the solid cylinder, the paper must be dipped in melted paraffin wax.

41. Tube for determining the density of a liquid by flotation.—Cut off a piece of *thin-walled* glass tube 12 in. long and $\frac{1}{2}$ in. in diameter, and grind the ends square on a sheet of emery-cloth. Cut two corks to fit tightly into the ends. Push one of these corks into the tube so that the outer surface is about $\frac{1}{4}$ in. inside the tube, and fill in the space with sealing-wax, finishing the end off flat with a hot piece of metal. Pour mercury into the tube till it floats upright, then insert the second cork, finishing off with sealing-wax as before. A strip of paper divided into millimetres may be rolled up and placed inside the tube, so that the depth of immersion may be directly read off.

48. Boyle's law tube.—Long limb 36 in., short limb 10 in., bore of tube 0·3 in. To close the end, cut the tube off square

and heat the *extreme end* by holding it at the edge of a blow-pipe flame. Continue heating, keeping the tube rotating, till the sides of their own accord come together and the end closes. If the inside is still slightly dome-shaped, press the end when hot on some flat metal surface, then well anneal.

The form of Boyle's law tube shown in Fig. 35 has the disadvantage that it is not easy to remove the mercury. Without complicating the instrument to any great extent, this difficulty may be overcome by making the two limbs out of separate pieces of glass, each connected by means of a short piece of thick-walled indiarubber tubing to a small glass T-piece. A piece of the same kind of rubber tubing on the third branch of the T-piece can be closed by means of a pinch-cock. The junctions of the rubber and glass must all be carefully bound round with fine copper wire, or the pressure of the mercury will force the rubber tubing off the end of the glass. This form of the apparatus has the further advantage that the tube can be easily cleaned and dried.

49. The long cylinder for containing the mercury may be made, as shown in the figure, from a short piece of wide glass tube (portion of a lamp chimney), fixed by means of a cork to a piece of glass tube closed at one end, and about 24 in. long and ¾ in. in diameter.

54. Spring balance.—The springs for the balances may be made by winding steel piano wire 0·0146 in. in diameter (No. 28 or 29 standard wire gauge) round a metal rod 0·14 in. in diameter. To wind on the wire, if a lathe is available, mount the rod in the chuck, if not, make a windlass arrangement with the rod for axle, and wind the wire in as close a spiral as possible, keeping the wire taut by allowing it to run between your fingers. In order to obtain a uniform spiral it is essential to feed on the wire in the manner shown in Fig. 120, where AB is the wire that is being wound on, and CD is the metal rod. The wire must be held so that the angle α may be as small as possible, without the wire as it goes on riding up on the top of the previous turn. After winding a considerable length in this way, remove the spring from the metal rod, and gradually stretch the spring beyond the elastic limit till, when released, the spires are just not in contact. Cut the spring up into lengths of 4 in. each, and twist the wire at either end into a loop. The wooden bases are 18 in. long, 1½ in. wide, and ⅜ in.

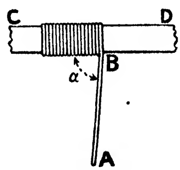

FIG 120.

thick, with a cross-piece, I (Fig. 40), of such a thickness that when the loop at the end of the spring is put over a nail on this cross-piece the spring is just clear of the wood. The scale may be divided by the method given in Exercise 8, or cardboard scales divided in mm. may be obtained and glued on the wood. A piece of strong cotton, with a knot to serve as an index, is tied to the spring. Hang a weight of 110 grms. on this string, and then pass another piece of cotton down the axis of the spring, and tie the ends to the loops at the ends of the spring. This cotton will form a check-string to prevent the spring being stretched beyond its elastic limit which would necessitate its being recalibrated. If it is preferred the use of a calibration curve can be avoided by making the scale to read directly in grammes. To make such a scale, obtain the readings on a mm. scale temporarily fixed alongside for stretching forces of 10 and 100 grms. Plot these values on curve paper, joining the two points by a straight line. Read off the position of the index for each whole 10 grms., mark these points on the instrument, and divide each interval into ten equal parts. In order to prevent the instrument slipping about when used on a flat surface, drive a strong needle through the wood near either end so that the point projects through for about $\frac{1}{10}$ in., then break off the head. These needle points are pressed into the paper when the spring balance has to be fixed. The two longitudinal strips of wood fixed alongside the spring are for the support of a strip of wood which serves to enclose the spring and protect it from injury, but which has not been shown in the figures in order that the spring might be seen.

71. Inclined plane.—Base 24 in. × 2 in. × $\frac{1}{2}$ in.; inclined part 24 in. × $1\frac{1}{2}$ in. × $\frac{1}{2}$ in.; prop (H, Fig. 57) 8 in. long. The hinge at B must be countersunk. The nails may be placed 1 in. apart. Cylinder (brass) $1\frac{1}{2}$ in. long and $1\frac{1}{2}$ in. in diameter.

73. Pulley.—The sheaf ought to be made of boxwood or some other hard wood, and be at least 3 in. in diameter. The axle may be about $\frac{1}{32}$ in. in diameter; the block is made either of wood or of a piece of bent band-brass.

79. Atwood's machine.—Upright 6 ft. × 3 in. × 3 in. Platforms C and D (Fig. 62) 4 in. × 4 in. The pulley is made out of three cardboard discs glued together. The diameter of each of the outside discs is $6\frac{1}{4}$ in., and that of the inside one 6 in. While the glue is drying the discs must be pressed flat between two boards. Take a piece of knitting needle about $2\frac{1}{2}$ in. long and pass it through a disc of cork about $\frac{3}{4}$ in. thick, then through the

centre of the cardboard discs, and finally through another cork disc. Coat the inside faces of the corks with a thickish glue, and adjust their positions till when the pulley is turned by the axle it runs true. The groove at circumference of the pulley can be smoothed by means of some fine sand-paper wrapped round a metal rod or the edge of a flat plate. The bearings for the pulley axle consist of two pieces of glass tube about $\frac{1}{4}$ in. long. The tube should be chosen of such a size that the axle just fits loosely. These pieces of glass are fixed to the wooden uprights by means of sealing-wax. If necessary the pulley must be balanced by weighting with sealing-wax till it will remain at rest when turned into any position. The thumb-screws for fixing the position of the platforms consist of an ordinary screw with a piece of brass soldered into the slot in the head. In order to prevent the screws damaging the wooden upright, a piece of sheet brass 3 in. × 2 in., with about $\frac{1}{8}$ in. of one of the longer edges bent round at right angles, is slipped between the inside of the wooden support of the platform and the upright. The thumb-screw presses on this metal plate. The construction of the falling platform, B, is shown in detail in Fig. 63. The spring, H, consists of a piece of clock-spring, and the catch is part of the pin to which the cord is attached, which is bent round at right angles and soldered to the front of the spring. The weights may be made of lead, and one pair should weigh about 250 grms., and the others 150 grms. The rider should weigh about 10 grms. and may be made of sheet brass. The best material to use for the cord is fine fishing line. Size H, level American Waterproof trout line does very well.

86. Hick's ballistic balance.—Length of suspending fibres 36 in.; platforms 4 in. × 4 in. Length of cross-pieces, C (Fig. 65), 8 in.

91. Dropping plate.—Base 4 in. × 4 in. Slide 10 in. high, 2 in. broad, and $\frac{3}{8}$ in. thick, and inclined about 85° to the horizontal. The slide is glued to a small wooden block in which there is a hole about $\frac{3}{4}$ in. in diameter. A screw which passes through this hole and a metal disc about 1 in. in diameter serves to clamp the slide, the large hole in the wood allowing the position of the slide to be adjusted. The upright block to which the tuning-forks are clamped is made from a piece of wood 3 in. × $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in., the bevelled face being inclined at about 60° to the horizontal.

107. Spherical mirrors.—It is possible to obtain watch-glasses which are segments of a sphere, and which, when silvered by the method given on p. 226, form mirrors with a sufficiently good figure

for elementary work. The silver may be protected by fastening the silvered watch-glasses together in pairs, one being silvered on the concave and the other on the convex surface. Such a pair of silvered watch-glasses will form a concave mirror on one side and a convex mirror on the other. A stand for the mirrors may be made by boring a centre-bit hole a little smaller than the mirrors in a piece of wood about ½ in. thick, then cutting the wood in two along a diameter of this hole. A saw cut is made parallel to the surface of the wood and the mirror slipped into this cut. This piece of wood may be glued upright on another piece forming a base.

114. Spectrometer.—Instructions for making a spectrometer which is quite sufficient for elementary work will be found in the Syllabus of the Course in Physics at the Royal College of Science, London (Published by Eyre & Spottiswoode, price one shilling). A good prism made of dense glass will be required.

122. Hypsometer.—The hypsometer may be made of either glass or brass tube, the latter will not crack. The tube FD, Fig. 88, is 14 in. long and 1¾ in. in diameter. A cork, C, pierced with a number of holes, serves to support the end of the tube AB.

128. Expansion of air.—The tube AB is 39 in. long, and has a bore of about 0·1 in. Before closing the end this tube must be thoroughly cleaned by washing in succession with nitric acid, water, caustic soda, and water, *then well dried by heating and blowing a current of air through by means of a bellows.* Blowing air through with the lungs is quite useless. If high values are obtained for the co-efficient of expansion, this is probably due to moisture, which has been left clinging to the side of the tube, becoming converted into vapour at the higher temperature.

132. The heater shown can be made by any tinman at a small cost.

138. U-tube.—Bore of tube ¼ in. Closed limb about 5 in. long, open limb about 8 in. long.

140. Bar magnet.—These may be made from tool steel 6 in. × ½ in. × ¼ in. Before hardening, file the ends square. Heat in a clear fire to a *bright* red heat, then quench in water. Magnetize by placing inside a coil through which a fairly strong current is passed. The magnets will require re-magnetizing from time to time.

148. Steel disc.—A wooden disc in which a magnet has been embedded will do instead of a steel disc. Take two discs of wood and hollow out a place in each into which the magnet will just fit. Then glue these discs together with the magnet in the hollow.

150. Dip needle.—The needle is made from a piece of clock-spring 6 in. long and $\frac{1}{2}$ in. wide. File the ends up to a point, and bore a hole at the centre of such a size that a large sewing-needle will fit tightly. If the spring is not unmagnetized heat it to redness and quench in water; polish with emery-cloth, and place it on a hot iron plate till it turns blue, then again quench. Pass a piece of needle about 1 in. long through the central hole, and fix the needle in place with sealing-wax. Place the needle on the two short glass rods fixed by sealing-wax to the top of two wooden uprights 3 in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{3}{4}$ in., and, either by filing the heavier end or weighting the lighter end with sealing-wax, adjust the needle till it will remain in any position. Magnetize by the method given in Exercise 144.

164. Gold-leaf electroscope.—The construction of the instrument is evident from Fig. 105. The cross-piece E, which is seen end on in the figure, ought to be about $\frac{3}{4}$ in. long with its edges and corners carefully rounded. The gold-leaf is best cut up on a gilder's pad, using a long knife with a blunt and *smooth* edge; a suitable size for the leaves being $2\frac{1}{2}$ in. $\times$ $\frac{5}{8}$ in. Coat the two sides of the cross-piece E with gum, being particularly careful that no gum gets on the lower edge. When the gum has got "tacky," lay the cross-piece first on one piece of gold-leaf, then on the other. If the gold-leaf is sucked round from one side on to the other by capillarity, it means that some of the gum has got on the edge of the cross-piece.

167. Electrophorus.—A piece of sheet ebonite 6 in. square and $\frac{1}{4}$ in. thick forms the "disc." The cap may be made from an ordinary tin plate such as can be obtained at most hardware shops, with a nail soldered at the centre of the upper surface. This nail is embedded in a rod of sealing-wax, or is cemented by sealing-wax inside a length of glass tube, which forms the handle. If glass is used it must be coated with shellac varnish.

168. Cone-shaped conductor.—This may be made from a wooden ball and a cone made of paper, so that the ball just fits into the base of the cone. The whole is coated with tinfoil. A cylindrical conductor with spherical ends can, in the same way, be made with two wooden balls, or with a ball cut in halves and a paper cylinder.

169. Ice-pail.—A tin can may be insulated on legs made of sealing-wax or ebonite (an ebonite stirrer).

181. Circular mercury cups.—A hole $1\frac{3}{4}$ in. in diameter is bored in a piece of wood 3 in. $\times$ 3 in. $\times$ $\frac{1}{2}$ in. A hole $\frac{5}{8}$ in. in diameter

is bored in a cork $\frac{7}{8}$ in. in diameter and $\frac{1}{2}$ in. long. The wood and cork are then glued on another piece of wood, and the wires carried in through fine holes, as shown in Fig. 113.

182. Galvanometer.—The compass box need not be circular, but may be square, the circular part of the one shown in Fig. 114 was made out of brown paper. The needle, 2 in. long with an agate centre, can be obtained from Messrs. Harvey & Peak, 56, Charing Cross Road, London, W.C., price 1*s*. 6*d*. The pivot on which the needle turns is formed of a fine needle-point fixed with sealing-wax into a hole in the base of the compass box. The divided circle is 4 in. in diameter, and may be obtained from most instrument dealers, price about 6*d*. The pointer is attached to the top of the centre of the needle by means of a spot of sealing-wax. The best material of which to form the pointer is aluminium wire (No. 26), but brass wire or a capillary glass tube will do. The ends of the pointer ought to be turned down so as only just to clear the surface of the divided circle. The coil consists of thirty turns of No. 22 covered copper wire wound on a wooden circle 7 in. in diameter. After winding on the wire, give it a good coating of shellac varnish.

THE END.

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